The California Water Sustainability Indicators Framework

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I. Executive Summary

Measuring environmental, social, and economic conditions and influences on these conditions is an important part of knowledge-building and adaptive management. The California Water Sustainability Indicators Framework (hereafter "Framework"), being developed as part of the California Water Plan (CWP) Update 2013, brings together water sustainability indicators that will inform us about water system conditions and their relationships to ecosystems, social systems, and economic systems. The evaluation of the selected sustainability indicators is anticipated to reveal how our actions or inaction can degrade or improve conditions that lead to water sustainability. The Framework is built around both statements of intent (e.g., objectives) and themes (e.g., water quality). Reporting indicator condition is based upon the principle of measuring how far a current condition is from a desired condition. The Framework is intended to support reporting of indicators to a wide array of water and environmental stakeholders, the public, and decision makers to build knowledge and to enhance adaptive decision-making and policy change.

The basis of the Framework is an overall vision for water-related sustainability indicators for California, including an understanding of sustainability, indicators, and related terms. Based on a generally agreed-upon vision among stakeholders in a given region, in the whole state, the proposed Framework operates through a series of inter-related steps, beginning with defining objectives and ending with reporting conditions relative to sustainability targets. Each step generally follows the previous step and completing all steps is necessary for a full evaluation of water resources sustainability. The Framework is designed to be scale-independent, so it can be applied from local to global scales. Ultimately, the Framework informs us how well we are sustaining the natural, social, and economic systems that we depend upon, at least in terms of water, and based on what we know about stresses to these systems, how we can improve degraded conditions.

Why Are We Doing This?

The mission of the California Department of Water Resources is to manage the water systems of California, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. To fulfill this mission, DWR coordinates preparation of the California Water Plan Update, Bulletin 160 (Water Plan), in collaboration with other state agencies. Providing a comprehensive statewide water reporting and management framework, the Water Plan is the State's strategic plan for developing and managing water resources statewide. Mandated by the California Water Code (Section 10005 et seq.) and updated every five years, the Water Plan sets forth a blueprint for water managers, legislators, and the public to consider options and make decisions regarding California's water future.

With a growing recognition that California's water systems are finite, and faced with climate change, growing population, and more stringent environmental requirements, decision-makers, water managers, and planners are becoming increasingly aware of the need to both sustainably manage water and respond to changing availability and constraints on water. In the Water Plan Updates 2005 and 2009, the State refocused attention on the sustainability of California's water systems and ecosystems in light of current water management practices and expected future changes. However, one recurring question from stakeholders has been, "How can we ascertain that the objectives of the Water Plan and the associated resource management strategies would lead to sustainable water use and supply for the State and its various hydrologic regions?"

To respond to the above concern, one of the guiding principles established for decision-making in the California Water Plan Update 2009 was: "Determine values for economic, environmental, and social benefits, costs, and tradeoffs to base investment decisions on sustainability indicators." However, there are major impediments to address the state's water sustainability using sustainability indicators. These include: inconsistent terminologies and definitions used; absence of a systematic analytic framework and methodologies for quantification of water sustainability indicators; and a potential lack of data to undertake the appropriate analysis to assess sustainability of water resources through the development and on-going tracking of a set of sustainability indicators. As part of the Water Plan Update 2013, DWR has initiated a process to develop a framework and a set of preliminary sustainability indicators. The developed framework will help us identify, compute, and evaluate a set of relevant sustainability indicators that would help monitor progress towards sustainability of natural and human water systems.

Who Are We Working With?

The core team of DWR, UC Davis, and USEPA scientists has put together a stakeholder-driven, collaborative, and transparent process for reaching agreement on a water sustainability vision through work team activities, meetings, workshops, and outreach. We also want to ensure that the Framework and analysis developed as part of this project have solid scientific and technical underpinnings and are defensible and well accepted by the peers in the field. We will use the Water Plan's extensive stakeholder participation processes for this purpose:

- DWR and partner agencies work teams – DWR staff work with USEPA and other agency staff and University of California, Davis technical experts.
- Water Plan's Statewide Water Analysis Network – convene and connect with leading experts to ground-truth the technical analyses.
- Sustainable Water Resources Roundtable - Bring in the latest perspectives on the methods and practices related to water resources sustainability.
- State Agency Steering Committee - weigh in overall State government coordination and perspective in the water planning process.
- Water Plan Public Advisory Committee – access views of a broad stakeholder group.

- Regional Forums – obtain regional perspective using regional and local relationships through DWR's Regional Offices, IRWM outreach activities, and Regional Forums.
- Tribal Advisory Committee - involve the California Native American Tribes in the state and regional planning process.
- Federal Agency Network - engage federal agencies in the state water planning process.

What Do We Mean By Sustainability?

The California Water Plan, 2009 Update, included a vision statement laying the foundation for how California can be sustainable in water use and management. The vision is that: *California has healthy watersheds and integrated, reliable, and secure water resources and management systems that: Enhance public health, safety, and quality of life in all its communities; Sustain economic growth, business vitality, and agricultural productivity; and Protect and restore California's unique biological diversity, ecological values, and cultural heritage.*

Generally speaking, "A system that is sustainable, should meet today's needs without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1983). The USEPA defines sustainability as "The satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends." The state of Minnesota adopted this definition of sustainable water use as part of their Water Sustainability Framework, "That which does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs." And there are many other definitions as well.

In order to help meet the vision of the Water Plan, we propose that sustainability be thought of in two main ways: 1) as a goal toward which we collectively strive, recognizing the inherent value of "becoming sustainable" and 2) an emergent property of collectively "acting sustainably", which affect small or large parts of the natural, social, and economic systems we rely upon. What this means in terms of this Framework is that we would measure our progress toward the goal of becoming sustainable by measuring how individual components of natural, social, and economic respond to our actions. So, sustainability indicators measure the condition of parts of the systems, and/or performance of our actions, as well as our distance from and progress toward a range of sustainability.

How Does the Indicators Framework Work?

The Framework is organized into steps corresponding to major procedural endeavors. Completing each step leads to subsequent steps and completing all steps is necessary for a full evaluation of water sustainability.

Step 1 Describe the overall vision for sustainability and define water sustainability and related terms

Step 2 Set goals corresponding to the vision, and measurable sustainability objectives; describe themes (e.g., water supply) and system processes
Step 3 Select indicators corresponding to the objectives and covering all themes and processes; define targets for each indicator; describe potential causes of change in indicator condition
Step 4 Collect data for each indicator, maintain and describe data provenance; analyze data according to distance from current state from target state and describe analytical steps; measure trend in condition and significance of trend
Step 5 Describe summary condition and trend in condition in report card; evaluate performance of system sectors
Step 6 Evaluate causes of condition departure from target condition and individual and programmatic actions that could maintain good conditions and repair poor conditions
Step 7 Describe contribution of evaluation to change in scientific knowledge, policy effectiveness, and public/decision-maker education

For the envisioned Framework, we will use the structure of a vision- objectives-indicators-metrics nested hierarchy. In the Water Plan Update 2009 there are goals, objectives, guiding principles, and resource management strategies in separate narrative tools directing actions and desired outcomes. The Framework is based upon "water sustainability objectives" and can be used to evaluate whether meeting the goals, objectives, and resource management strategies of the Water Plan leads towards sustainable water use and supply in California. The water sustainability objectives derive their meaning and much of their text from the Water Plan statements of intent, but attempt to make clearer connections with the idea of sustainability across ecosystem, social system, and economic system. A sequence of steps begins with selecting goals and objectives (Figure 1, going from left to right), the selection of indicators for each objective, evaluating indicator condition relative to reference conditions, and reporting indicator conditions to inform knowledge development and policy decisions.

Table 1. Glossary of terms

Term	**Definition**
Objective	Objectives are measurable descriptions of desired outcomes for particular aspects of the system's condition.
Indicator	Indicators are typically qualitative or quantitative parameters that are familiar from monitoring programs (e.g., streamflow), becoming indicators when selected to represent parts of ecological, social, or economic systems.
Index	An index is an aggregation of indicators that may convey a story about a system, or part of a system.
Theme/domain	Themes and domains are types of category (i.e., collection of like attributes) and are terms of art referring to large parts of natural or social systems (e.g., landscape condition).
Metric	Metrics are measurable characteristics of systems and are the building blocks of indicators, and thus the foundation of condition assessment. Examples include streamflow, groundwater level, native fish population size, and water temperature.

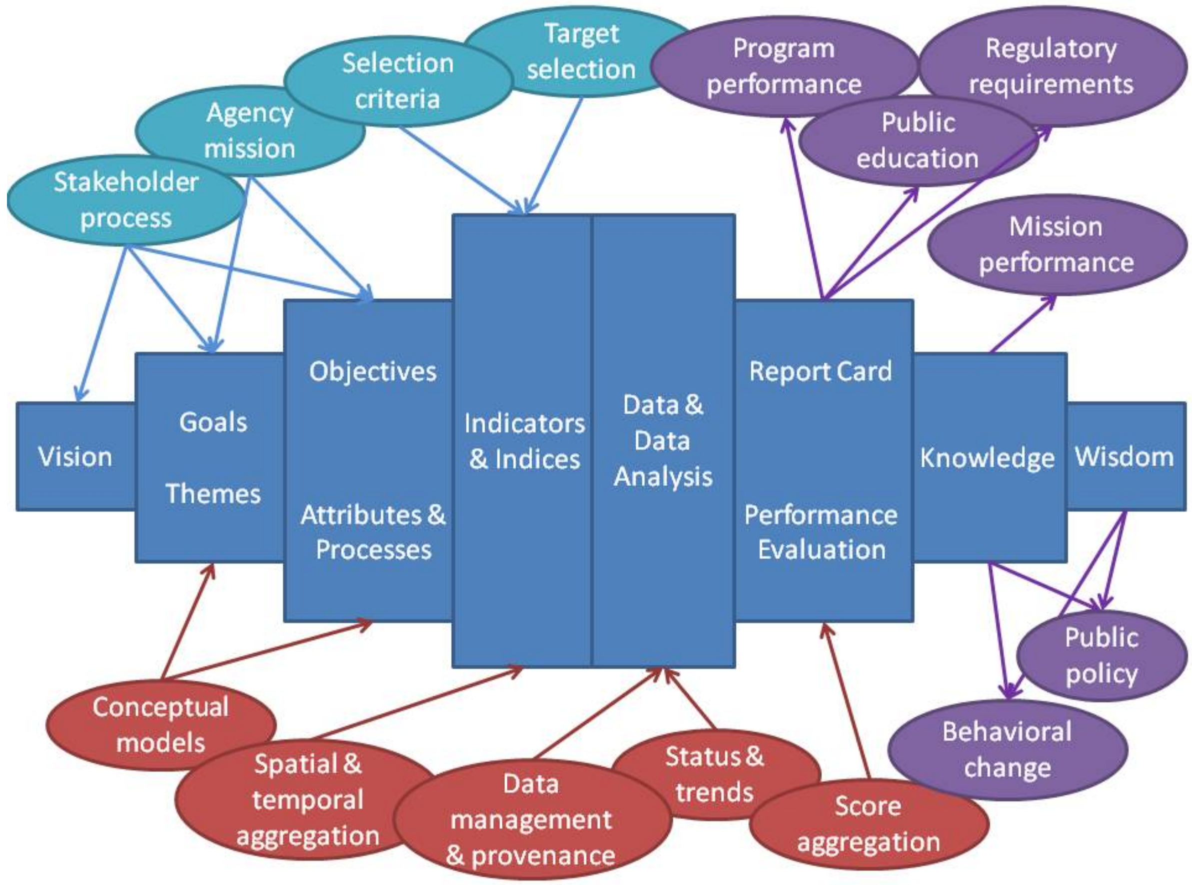

Figure 1 Sustainability Indicator Framework and procedural steps.

Where Can the Framework be Used?

One anticipated utility of the Framework is that it will provide a toolbox, useful templates, and a set of illustrative examples for IRWM regions to conduct water sustainability analysis for local and regional water management. By utilizing this Framework, local and regional water and other agencies comprising the IRWM regions will be able to improve their sustainability through an evaluation of condition and trends of relevant indicators reflective of their particular needs. The process will also help identify issues and data gaps to inform future data monitoring needs on a local and regional scale to enable better quantification of water sustainability in the future. Similar to the case for the state as a whole, the indicator analysis on a local and regional scale by the IRWM regions is also expected to highlight policy needs for ensuring the local and regional water sustainability.

When Will We Finish the Framework?

A team from UC Davis, with input from Water Plan Advisories Committees, DWR and USEPA Region 9 scientists, and others involved in the Water Plan, has formulated an approach that is consistent with both the best scientific practices for indicator systems and the California Water Plan. The approach is based upon previous DWR-funded projects by the UC Davis lead scientist (Shilling et al., 2010 & 2011). We acknowledge that defining and developing the Framework will be an ongoing, iterative, and evolutionary process. As we continue to receive stakeholder feedback and learn from testing the Framework in a region of California, we will accordingly refine the Framework as part of the Water Plan Update 2013 process. The final version of the Framework will be included in the 2013 Update.

How Are Indicators Connected to Ecological and Water Footprints

The basic idea of the ecological footprint is that our activities and physical infrastructure measurably affect an area or other portion of ecosystems (the "ecological footprint"). For example, the land-area required to supply an average US resident with food is ~2.4 acres. The irrigation and other water requirements for providing food and other needs can be measured as a volume of water, (the "water footprint"). In the US, the per capita water footprint is 2,480 m^3/yr, the largest in the world (Hoekstra, 2009). These approaches for measuring our effect on different attributes of natural systems rely on a combination of understanding how human endeavors occur in ecological domains and how much of an ecological attribute may be affected. Indicators are a way to measure these endeavors and ecological attributes. This provides a connection between the more traditional world of condition indicators and a comprehensive way of measuring and describing our effects on natural systems.

In Phase II of the Water Sustainability Indicators project, we will include the water footprint as an important index of human impacts to water systems. It will not replace other indicators, but will serve as a composite index of multiple indicators of human uses of water and impact on natural systems.

II. Approach

The California Water Sustainability Indicator Framework is composed of a cycle of process steps that build upon each other. The cycle begins with defining what is meant by sustainability and other terms and completes one cycle by informing policy and decision-making. The process is intended to be part of a cycle of adaptive learning and action. The indicators and the process of developing, analyzing, and interpreting them are not intended to stand alone, so links are described with regional planning, ecosystem services, and the idea of a water footprint.

II.A Process Steps

Step 1 Agree on Sustainability and Other Definitions

Sustainability has many definitions. The USEPA defines sustainability as "The satisfaction of basic economic, social, and security needs now and in the future without undermining the natural resource base and environmental quality on which life depends." The state of Minnesota adopted this definition of sustainable water use as part of their Water Sustainability Framework: "That which does not harm ecosystems, degrade water quality, or compromise the ability of future generations to meet their own needs."

In order to help meet the vision of the Water Plan, we propose that sustainability be thought of in two main ways: 1) as a goal toward which we collectively strive, recognizing the inherent value of "becoming sustainable" and 2) an emergent property of collectively "acting sustainable", which affect small or large parts of the natural, social, and economic systems we rely upon. What this means in terms of this Framework is that we measure our progress toward the goal of becoming sustainable by measuring how individual components of natural, social, and economic respond to our actions. So, sustainability indicators measure the condition of parts of the systems, and/or performance of our actions, as well as our distance from and progress toward a range of sustainability.

Step 2 State and Define Water Sustainability Vision, Goals, and Objectives

Society expresses its intent through a variety of mechanisms, including policies, stakeholder goals, etc. Social intent is an important organizing principle for reporting conditions and planning for sustainability. The California Water Plan (CWP) vision statement expresses the overall intent of the Plan in a very general way. The Water Plan process and regional water planning are also very inclusive, thus “social intent” here should be thought of as the product of a broader governance process than by single agencies or the Legislature. Because other statewide plans express intent for actions within their spheres of responsibility (e.g., the California Transportation Plan), an alignment of vision statements is an important activity. This is not the same as developing a common vision, so much as a coordination of intent among public entities and other stakeholders. To use this approach, or any similar way of reporting conditions according to social expectations, policies, etc., it is critical to define and describe these expectations.

Define Goals and Objectives in a Stakeholder Context

In the Framework, a goal is a broad statement describing where a community or society would like to end up, an objective is a more detailed and measurable aspect of broader goals, and indicators are the ways that we measure achievement of objectives and progress toward goals.

Goals are often narrower expressions of intent than vision statements and describe the desired outcome of a system or set of practices. Goals are often broad statements, sometimes with several possible pathways to the outcome. The term “objectives” is often used in the same way as the term “goals”; more often objectives are intended to convey a more exact and measurable desired outcome. An example of a <u>goal</u> from the 2009 California Water Plan (CWP) is “Water resource and land use planners make informed and collaborative decisions and implement integrated actions to increase water supply reliability, use water more efficiently, protect water quality, improve flood protection, promote environmental stewardship, and ensure environmental justice in light of drivers of change and catastrophic events.” A common structure for these systems is a vision-goals-objectives-indicators-metrics nested hierarchy (see Appendix C for global examples). The 2009 CWP does not have this structure. Each list of goals, objectives, guiding principles, and resource management strategies are separate narrative tools directing actions and desired outcomes.

Objectives (CWP, 2009)

1. Expand integrated regional water management
2. Use and reuse water more efficiently
3. Expand conjunctive management of multiple supplies
4. Protect surface water and groundwater quality
5. Expand environmental stewardship
6. Practice integrated flood management
7. Manage a sustainable California Delta
8. Prepare prevention, response, and recovery plans
9. Reduce energy consumption of water systems and uses
10. Improve data and analysis for decision-making
11. Invest in new water technology
12. Improve tribal water and natural resources
13. Ensure equitable distribution of benefits

The Sustainability Indicators Framework is based upon “sustainability goals and objectives” (table 2). The goals and objectives were derived primarily from the language and intent expressed in the Resource Management Strategies from the 2009 Update. The RMS were used because they provided the most detail and clearest statements of intent in the Plan, which aids in the development of corresponding indicators, which are in turn used to measure condition and performance of social and natural systems affected by the Plan. The CWP Objectives were also referred to, in order to ensure consistency with the several ways that the Plan describes sustainable management of water.

The sustainability objectives can be used to evaluate progress toward meeting the principles, goals, and vision of the CWP. In order to do this, an intentional series of relationships would be established among the goals, objectives, strategies and principles. These sustainability objectives derive their meaning and much of their text from the 2009 statements of intent, but they make clearer connections with the idea of sustainability across environmental, economic, and equity/social considerations (the 3 E's). These considerations vary in how they are defined and how much they overlap. In the case of the Framework, "environmental" refers to natural attributes and systems, including those that people take benefit from; "economic" refers to financial and non-financial values that affect or make up economic systems; and "equity" refers to fair and even access to benefits and decision-making for all communities. Implementing the objectives will depend upon interaction with impacted communities and tribes in order to ensure more equitable distribution of benefits and participation in decision-making across all objectives.

Table 2. Proposed sustainability goals and objectives for the California Water Plan, Update 2013. In this case, sustainability is defined to mean the maintenance of environmental, economic, and equity/social (the 3 Es) conditions for future generations. Every goal and objective is intended to meet the 3Es conditions.

Proposed Sustainability Goals and Objectives	**Relationship to Water Plan 2009**
Goal 1: Manage and make decisions about water in a way that integrates water availability, environmental conditions, and community well-being for future generations.	Reflects overall goal of sustainability
Goal 2. Improve water supply reliability to meet human needs, reduce energy demand, and restore and maintain aquatic ecosystems and processes Objectives: Increase water recycling; Increase water use efficiency; Reduce water demand; Increase water supply.	CWP Objective 2, 9; RMS Reduce demand
Goal 3. Contribute to social and ecological beneficial uses and reduce impacts associated with inter-basin water transfers and to the Delta. Objectives: Improve regional water movement operations and efficiency; Investigate new water technologies.	CWP Objective 1, 2, 7, 11, RMS Operational efficiency
Goal 4. Increase quantity, quality, and reliability of drinking water, irrigation water, and in-stream flows Objectives: Increase conjunctive management of new and recycled water from multiple sources.	CWP Objective 3, 12, 13; RMS Increase water supply
Goal 5. Safeguard human and environmental health and secure California water supplies Objectives: Protect and restore surface water and groundwater quality; Protect the natural systems that maintain these services.	CWP Objective 4; RMS on water quality; chapter 4 discussion of water quality sustainability indicators

Goal 6. Protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes Objectives: Practice, promote, improve, and expand environmental stewardship.	CWP Objective 5, 12, 13; RMS Natural Resources
Goal 7. Integrate flood risk management with other water and land management and restoration activities.	CWP Objective 1, 6, 12, 13; RMS Improve flood
Goal 8. Support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water resources management systems Objectives: Improve and expand monitoring, data management, and analysis.	CWP Objective 10; various RMSs; CWP Vol. 1 Chapter 6 Integrated Data and Analysis

Step 3 Select Indicators and Corresponding Targets

Indicators provide the connection between statements of intent (e.g., goals) and measurable aspects of natural and human systems. Because of the importance of the indicators in determining findings and basing decisions, the indicators themselves should be carefully chosen. Similarly, target or reference conditions against which to compare current conditions for each indicator should be transparently and carefully chosen.

Quantitative and Qualitative Indicator Selection

Evaluating progress toward measurable objectives is the primary intent of the Framework. To carry this out, representative and practicable indicators are selected and evaluated over time. Explicit criteria must be used to select indicators to ensure that the resulting evaluation is robust and usable in decision-making (Appendix B). Although all are important criteria, it is possible that a really good indicator does not meet all criteria; however, each indicator should meet most of these criteria and should meet at least the first 3 criteria. These criteria include:

- system representation;
- sensitivity to change over time;
- supports management decisions and actions;
- availability of high-quality data;
- long-term data affordability; and
- independence of indicators from one another.

One important characteristic of indicators is whether they are “leading” or “retrospective”. Leading indicators tell us something about what may happen or is going to happen. For example, if our goal is improve watershed and floodplain conditions, then one way to project benefits from surface to ground-water benefits is by measuring the proportion of aquifer recharge areas that is functional and protected from development. Un-developed recharge areas will provide future benefits to stream flows and consumptive water use. Retrospective indicators tell us about what has already happened to conditions and processes. For example, measuring river contributions to aquatic habitat and water supply needs in response to El Nino and La Nina conditions tells us about current or recent conditions.

There are thousands of possible indicators to choose from to describe how well systems are performing relative to sustainability goals and objectives. Developing this Framework included the investigation of several dozen indicator systems from around the world (summarized in Appendix C). Candidate indicators from these global systems and from more familiar programs in California were evaluated relative to the indicator selection criteria (Appendix B) and are listed in Appendix D. The overall goal for the indicators as a whole was to identify a set of indicators that efficiently covered the sustainability objectives, as well as covering various sectors of concern (e.g., water quality). An additional goal was to include indicators that are the most informative about conditions and changing conditions and sustainability in general. These indicators are a viable library of indicators for regional evaluations of condition using the Framework, for example, in IRWM planning and implementation.

An example of indicators that the Water Plan 2009 included are shown in the text box below. These came from the Sustainable Water Resources Roundtable (http://acwi.gov/swrr/), a 10-year old national discussion group that includes many California members. Although this list does not show exactly how one would measure each of these indicators, it provides a synopsis of some possible indicators to understand water sustainability.

Sustainable Water Resources Roundtable: Recommended Indicators

- 1. Water availability. People and ecosystems need sufficient quantities of water to support the benefits, services, and functions they provide. These indicator categories refer to the total amount of water available to be allocated for human and ecosystem uses
    - Renewable water resources. Measures of the amount of water provided over time by precipitation in a region and surface and groundwater flowing into the region from precipitation elsewhere.
    - Water in the environment. Measures of the amount of water remaining in the environment after withdrawals for human use.
    - Water use sustainability. Measures of the degree to which water use meets current needs while protecting ecosystems and the interests of future generations. This could include the ratio of water withdrawn to renewable supply.
- 2. Water quality. People and ecosystems need water of sufficient quality to support the benefits, services, and functions they provide. This indicator category is for composite measures of the suitability of water quality for human and ecosystem uses.
    - Quality of water for human uses. Measures of the quality of water used for drinking, recreation, industry, and agriculture.
    - Quality of water for the environment. Measures of the quality of water supporting flora and fauna and related ecosystem processes.
    - Water quality sustainability. Composite measures of the degree to which water quality satisfies human and ecosystem needs.
- 3. Human uses and health. People benefit from the use of water and water-dependent resources, and their health may be affected by environmental conditions.
    - Withdrawal and use of water. Measures of the amount of water withdrawn from the environment and the uses to which it is put.
    - Human uses of water in the environment. Measures of the extent to which people use water resources for waste assimilation, transportation, and recreation.
    - Water-dependent resource use. Measures of the extent to which people use resources like fish and shellfish that depend on water resources.
    - Human health. Measures of the extent to which human health may be affected by the use of water and related resources.
- 4. Environmental health. People use land, water and water-dependent resources in ways that affect the conditions of ecosystems.
    - Indices of biological condition. Measures of the health of ecosystems.
    - Amounts and quality of living resources. Measures of the productivity of ecosystems.
- 5. Infrastructure and institutions. The infrastructure and institutions that communities build enable the sustainable use of land, water, and water-dependent resources.
    - Capacity and reliability of infrastructure. Measures of the capacity and reliability of infrastructure to meet human and ecosystem needs.
    - Efficacy of institutions. Measures of the efficacy of legal and institutional frameworks in managing water and related resources sustainably.

CWP 2009, Vol. 1, pg 5-19

Qualitative indicators are important ways of describing condition and changing condition and assessing sustainability. This type of indicator is not typically included in indicator frameworks, potentially because of the perception that measuring condition or change in this way is too inexact and data acquisition too challenging. However, there are both indicators and methods for data collection that could contribute to understanding water sustainability using this approach.

Examples of qualitative indicators relevant to water sustainability include: "Historic amounts and availability of anadromous fish"; "Historic flooding conditions (extent and timing)"; "Historic fire conditions"; "Historic availability of clean drinking water from surface or ground sources"; "Community satisfaction/happiness"; "Equitable access to decision-making".

Collecting data for these indicators can be based in surveying methods, meaning talking to select groups or randomly-selected groups of people about what conditions they observe and have observed over time. Another way would be to review historic (European) written accounts of conditions before and during modification of different systems, such as in newspapers, journals, and technical papers. Understanding the use of these methods is important in developing cost estimates for collecting data for selected indicators. One approach that would be useful is to interview tribal elders about conditions that they recall and how those conditions have changed over time. A similar approach could also be used for non-tribal elders. Interviewing typically requires a one-on-one interaction between the subject of the interview and a paid interviewer. For the interview to be meaningful, several criteria need to be met: trust between the parties, an understanding of the interviewer of the culture and situation of the interviewee, and support for the time investment by both parties (as needed). Using this information to inform indicators requires coding and otherwise interpreting the interview material enough to inform the assessment of sustainability. Another approach that could be useful is to survey traditional or other experts using structured questionnaires. In this case, criteria relating trust and support may still be important. The output from this approach is quantification of qualitative responses about conditions and changing condition.

Select and Define Indicator Targets in Open Process

Comparing indicator condition against reference values, or targets, is a critical requirement for using indicators to inform condition assessments. These targets could be changed in future assessments, with corresponding corrections of past scores. A critical aspect of defining targets is that it should be carried out in an open and inclusive process. These targets could be based on historical conditions, desired future conditions, legal thresholds, current or anticipated physical limits, or some other value. These targets provide the context for interpreting indicator results — a number against which current status and trends can be compared. For instance, a high water temperature or an increasing trend in water temperature only tells us something meaningful about the risk of this condition to cold-water fish if we know at what temperature fish will be adversely affected, and whether the current trend is moving closer to or further away from that temperature threshold. For salmonids, temperatures above 17^{o}C begin to affect

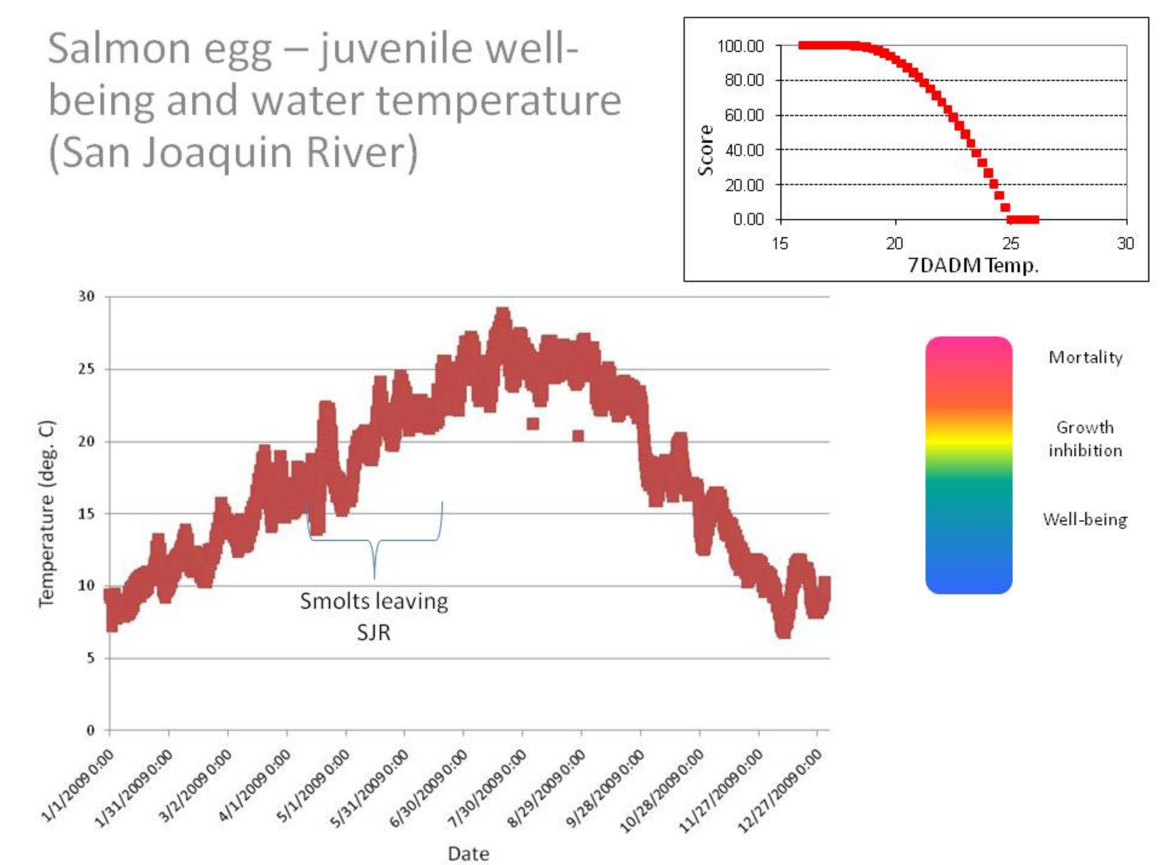

Figure 2. Comparison of salmonid young well-being to San Joaquin River water temperature. Inset graph: relationship between temperature and score for water temperature, based upon temperature sensitivity of salmonid young.

growth and survival, so one way to address water temperature is through its effect on salmonid survival (Figure 2). This means that any surface water temperature in streams bearing salmonids, and other cold-water fish, can be converted into an equivalent sustainability score, based on the idea that a management goal is the growth and survival of salmonids (Figure 2). A reference value is a quantity/value of an indicator that reflects some legal or physical threshold, desired goal or target, or historic and/or pristine condition, according to what is most meaningful for the assessment and reporting purpose, and supported by science. The selection of reference values is as important as the selection of the indicator itself because, without this baseline, it is difficult to assess the magnitude of change objectively, whether the magnitude of change is important, or if any efforts at improving conditions are succeeding (National Research Council, 2000).

Step 4 Provide Detailed Data Provenance and Analysis

This step is the data collection, data management, and data analysis step in the Framework. Data provenance is a term describing the path of data into the analytical framework, including where the data came from, what was done with it, and what was found out.

Indicator Data

Most indicators are chosen because information is available or is likely to become available to inform evaluation. Quantitative indicators are typically parameters that are familiar from monitoring programs (e.g., # spawning salmon) that become indicators when they are chosen to represent important parts of social-ecological systems. Because of the special role that indicators play in public education and decision-making, data sources should be carefully tracked and their provenance recorded through the indicator framework process. Data provenance refers to the described pathway that data for each selected indicator takes to become meaning as part of indicator evaluation. This pathway begins with justification for why a particular dataset is chosen to data management in a retrievable form linked to reporting on indicator condition.

This provenance pathway continues seamlessly with data analysis and reporting, which can be organized using the scientific workflow technique (Appendix E). Scientific workflows offer both a theoretical as well as a practical way for building a comprehensive environment for data management, analysis, and decision support. Scientific workflows combine scientific data and process workflows, and provide a graphical interface to manage the pipeline of steps of a scientific problem (Ludäscher et al 2009). One can think of scientific workflows as similar to a flowchart, where the various nodes represent computational tasks and the lines connecting each step are the informational inputs and outputs for each step. Each step can either be automated, such as an analytical task, or semi-automated, where external input and responses are required to complete the steps.

Distance to Target

Comparing indicator-parameter values to a reference or target condition is a critical step in the Framework. It is where sustainability meaning is attached to the data. There are a variety of ways to measure and normalize measurement of parameter conditions to target or reference conditions (see Appendix A for more detail).

In the Framework, normalization is carried out where each indicator is evaluated compared to a pair of reference or standard values (axiological normalization). Typically, there is a reference for “poor condition” (score = 0) and “good condition” (score = 100). When this is done for each indicator and each time point, the result is a “distance to target” value that can be on a 0-100 (or similar) scale. An important benefit of comparing indicator condition to targets is that scores can be combined across very different indicators (e.g., water temperature and fish tissue mercury concentrations), whereas otherwise this would not be possible. Because all indicator conditions are quantitatively compared to a target, they will all be normalized to the same scale — distance to target. Once the normalization takes place, the new values, ranging from 0 to

100, mean the same thing and can therefore be compared, or aggregated. Because environmental and socio-economic processes and conditions rarely respond to influences in a linear fashion, evaluating indicators relative to reference conditions must also take into account these non-linear responses. For example, evaluation of water temperature should follow a non-linear function because biological processes may respond non-linearly to changes in temperature (figure 3). Other processes or attributes may have a linear relationship, or power relationship to sustainability score (figure 3).

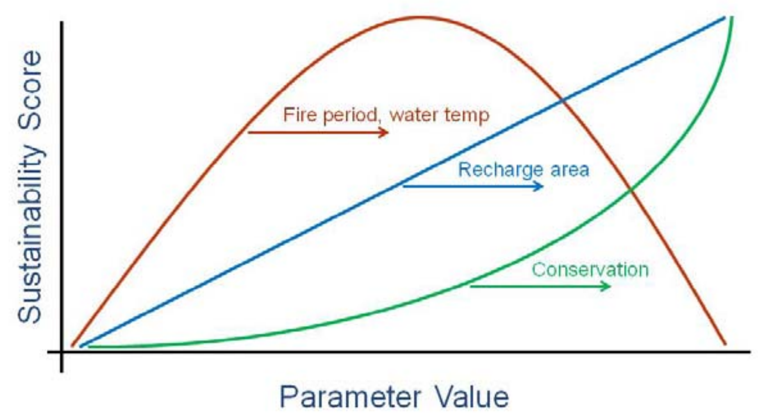

Figure 3 Non-linear relationships between parameters and equivalent sustainability scores

Trends Analysis

Changes in ecosystem characteristics over time are an important type of analysis and one of the most valuable types of information conveyed with indicators. Somewhat counter-intuitively, they are also rarely conducted using appropriate statistical techniques. Analysis of trend in time series data is necessary to determine if conditions in a waterway, community, ecosystem, or watershed are improving or deteriorating. One of the most common techniques for determining trend is linear regression. However, linear regression requires certain data characteristics, such as normal distribution of values, which are not easy to assess in small data sets. Distribution-free trend analysis is ideal due to the unknown nature of the data, so non-parametric tests are preferred. Of the various commonly used options, the Mann-Kendall rank correlation trend test is the strongest (Berryman et al. 1988). It is appropriate for data that are not normally-distributed, tolerates missing values, and is relatively unaffected by extreme values or skewed data. Related to the Mann-Kendall test, the Seasonal-Kendall test can be used to determine whether or not significant changes have occurred over time, while taking into account variation due to seasonal effects (Hirsch *et al*., 1982; Hirsch and Slack 1984; Esterby 1996). In contrast to this non-parametric approach, Nur (appendix to Collins et al., 2011) proposes the use of fitted regression models to log-transformed values for environmental variables, using bird abundance as an example. Nur incorrectly characterizes non-parametric tests as not being “quantitative” (e.g., the B-slope estimator in Seasonal-Kendall analysis; Hirsch et al., 1982). However, he does make a good case for carefully using quantitative, parametric trends analyses, at least on changes in populations of various biota and possibly other environmental attributes, over time. He also points out that auto-correlation should be measured in trends analyses, in order to estimate the effect on slope magnitude and confidence.

Variance and Confidence

The degree of certainty in the indicator evaluation results depends on two conceptual questions: whether good indicators were chosen and how well the data presented for each indicator accurately reflect the real status or trend in the metric(s). The first of these questions pertains to the indicators themselves and how well they address the objectives or attributes they are meant to represent. Certainty about the indicators depends on four main factors: Importance, understanding, rigor, and feasibility. The second question pertains to statistical confidence in the data presented for each indicator. The available data may contain a variety of sources of uncertainty including: measurement error, uncertain or inappropriate use of the sampling frame, sampling error, and process error. Any of the above sources of uncertainty affects confidence in the estimates of status and reduces the ability to detect trends over time. For some indicators quantification of different sources of uncertainty in the data may be possible, but in many cases there are limitations to providing a qualitative description of the likely sources of error and associated magnitude. Reporting confidence, certainty, and/or variance is important to building trust for the indicators framework.

Step 5 Report Card

Goals	Measurable Objective	Condition	Trend	Confidence
Water quality and supply for natural and human communities	Water quality for aquatic health	50	↔	Medium-high
	Maintain natural stream flows	55	n/a	Medium
Protect and restore native animals and plants	Native birds	100	↔	Medium
	Native invertebrates	46	↔	High
	Native fish	49	↔	High
	Agricultural/urban development	90	n/a	Medium
Protect and enhance habitats, ecosystems, and watersheds	Protect aquatic connections	77	n/a	Medium-high
	Protect landscape connections	33	n/a	High
	Maintain natural production and nutrient cycles	82	↓	Medium
Maintain and restore natural disturbance	Restore natural fire regimes	9	↔	Medium
	Encourage natural flooding, while protecting people	50	n/a	Low
Improve social and economic conditions & benefits from healthy watersheds	Enhance wildlife-friendly agriculture	83	↑	Medium-high
	Improve community economic status	51	↓	High

Figure 4 Sample report card, Feather River Basin (Source: Shilling et al., 2010)

The Framework report card is the formalized reporting mechanism for indicator condition, trend in condition, and confidence in the findings. There are a variety of criteria for performance of an indicator report card. It should be understandable to the audience who is intended to benefit from indicator evaluation; it should be accurate and transparent; and it should aggregate information to a degree that does not mask especially poor or good conditions in the study area.

Our strategy is to develop a very detailed reporting system in report form, or online, with resolution at a subunit scale and values provided for every metric and indicator (example: http://ice.ucdavis.edu/waf). A summary report card could then also be provided that measures progress toward meeting objectives and shows summary trend and confidence information (e.g., figure 4).

Effective online reporting of the Framework requires a model for the corresponding web framework (figure 5; described in more detail in Appendix F). In this model, information is sorted in two main ways in reporting – geographic and by indicator. These are likely to be common ways that people search for information, but there may be other mechanisms. Another possibility is to develop a real-time, online indicator system that takes parameter values available online and uses the steps here to convert data streams into measures of sustainability in an automated way. A third possibility is to provide ways for data entry to be more automated and mechanisms for a user/decision-maker to adjust data sources, data analyses, and normalization approaches to create ad hoc “what-if” scenarios. This more dynamic system could be a decision-support tool for assessing sustainability and to improve decisions intended to support sustainability.

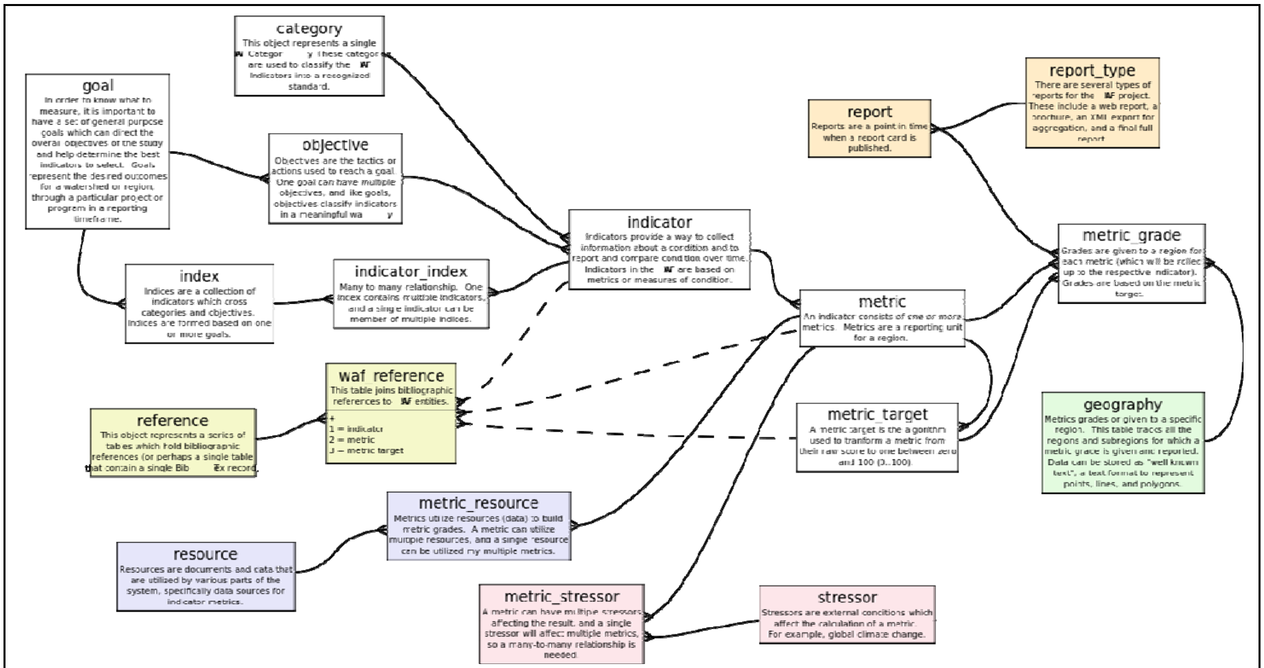

Figure 5. Data model for web-version of a sustainability report card.

Step 6 Knowledge Building and System Performance

Evaluating indicators provide a periodic or continuous stream of several types of information. This information contributes to building knowledge about how systems work, how they are changing, how they might change, and what we can do to ensure or build sustainability in these systems. One type of contribution is improved knowledge about the functioning of usually-complex systems by the public and decision-makers. This can help management agencies and elected bodies to make tough decisions if others understand what led to that decision. In order to carry out this function, the Framework should include indicators that both measure progress toward meeting social goals and objectives and represent many aspects of complex systems. Another function is measuring performance of programs and management actions intended to be sustainable. This last function is embedded in sustainability objective 7, which relates to the deliberate use of scientific information in decision-making.

Step 7 Policy and Behavioral Response

Achieving sustainability requires measuring social, economic, and environmental condition and developing actions and policies to respond to degraded conditions and to promote improving conditions. Developing appropriate responses requires accurate condition assessments and linkages between influences and condition change. Developing responsive behaviors and policies is the hard work of sustainability indicator frameworks. It often requires negotiation among competing interests, who may question the information provided by the Framework. To help with this process, the report card should convey the relative confidence, or certainty, in the condition assessment. Condition and trends assessment combined with confidence and linkage models can provide the basis for sustainable policy and behavioral responses.

II.B Intersection of Indicators with Natural and Management Systems

Indicators and IRWM Regions and Planning

The proposed Water Resources Sustainability Indicators Framework is envisioned as a transparent and documented framework for evaluating California's water sustainability, embodying a clear and consistent stakeholder driven vision, a step by step methodology, a suite of indicator reporting methods, a set of consistent terminologies, and important references. It is conceived as a tool for monitoring progress towards the state's water resources sustainability through meeting the objectives of the California Water Plan through a set of relevant, quantifiable indicators. One of the significant anticipated utility of the Framework is that it will provide a toolbox, useful templates, and a set of illustrative examples for IRWM regions to conduct water resources sustainability indicators analysis for local and regional water management. By utilizing this Framework, local and regional water agencies comprising the IRWM regions may be able to improve their water resources sustainability through an evaluation of condition and trends of relevant indicators reflective of their particular needs. The process will also help identify issues and data gaps to inform future data monitoring needs on a local and regional scale to enable better quantification of water resources sustainability indicators in the future. Similar to that for the state as a whole, the indicator analysis on a local and regional scale by the IRWM regions is also expected to highlight policy needs for ensuring the local and regional water resources sustainability. In the pilot phase of the Sustainability

Indicators Framework project, we will work with one or two IRWM regions to determine how the proposed approach can be used and refined to suit the needs of regional and local planners and organizations.

Indicators and Ecosystem Services

Ecosystem services need to be considered in developing the California Water Sustainability Indicators Framework (see Appendix G for a detailed discussion on ecosystem services). Drawing from the scientific literature, a conceptual model for ecosystem services can be built connecting ecosystem processes (e.g., nutrient cycling) and features (riparian forest) to the provision of ecosystem services (e.g., pollination by native pollinators), which in turn provide benefits to humans (e.g., increased agricultural production). Each of these steps can have associated indicators (figure 5), which not only help to describe and quantify the ecosystem services, but can serve to link this concept to the Sustainability Framework.

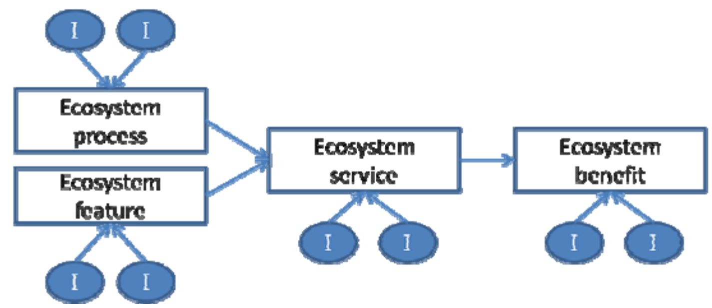

Figure 5 Indicators ("I" in circles) in the ecosystem services model.

A companion effort is underway by the Water Plan work team to quantify ecosystem services and the associated benefits. The Framework effort will closely collaborate with the Water Plan ecosystem services effort to ensure consistency between the two.

Indicators and Ecological and Water Footprints

An ecological footprint is a measure of the impact humans have on the earth. In the simplest terms, it is a measure of resource consumption and waste production compared with the planet's natural ability to generate new resources and absorb waste. Calculations are based on land area required to produce and assimilate these resources and wastes within six land use types: cropland, grazing land, fishing ground, forest land, built-up land, and the uptake land to accommodate the carbon footprint (a measure of carbon dioxide release and natural absorption) (Global Footprint Network 2010).

The ecological footprint is a useful indicator for determining sustainability because it incorporates many facets of consumption and renewal in a manner that is measurable and useful in management (Wackernagel and Yount 1998).

The relevance of the ecological footprint with regards to the California water sustainability indicator framework is evident in the water footprint, which is derived conceptually and is related to the ecological footprint idea. The water footprint is the relationship between direct or indirect uses of water used to produce goods and services consumed by humanity. Agricultural production accounts for most of global water use, but drinking, manufacturing, cooking, recreation, washing, cleaning, landscaping, cooling, and processing all contribute to water use (Hoestra et al. 2011). In addition to these direct water uses, indirect uses such as water impacted by pollutants, chemical or temperature, contribute to the water footprint (see Appendix H for more discussion). We will use the water footprint as an index in implementation of the Framework. It will be composed of multiple indicators of water use and, as an impact index, will stand alongside the indicators of system condition.

A companion effort "California Footprint Sustainability Indicators for Decision Support" led by the USEPA is underway. The two major components of this effort are the development of ecological and water footprints. Global Footprint Network will lead the ecological footprint analysis, while DWR and UC Davis, in partnership with USEPA, will lead the development of the water footprint analysis. The Framework effort will closely collaborate with the USEPA effort to ensure consistency among the two.

Indicators and Water Plan Scenarios

An important component of the Water Plan is development of potential scenarios for populations, land-use patterns, irrigated crop area, water conservation, precipitation, and temperatures. In combination, these parameters can be used to model water management under possible future conditions. In an attempt to describe boundary states for possible future conditions, the 2009 Update of the Water Plan solved for a combination of fixed conditions for each parameter in the following 3 scenarios: Current Trend, Slow/Strategic Growth, and Expansive Growth.

The primary parameters in scenario modeling can be treated as drivers in the water cycle that have measurable responses: environmental, agricultural, drinking, commercial/industrial, and all water. Indicators for both the drivers and responses can be and are included in the Framework. This allows potential future conditions and management responses to be modeled in the context of the Sustainability Indicators Framework.

Drivers	Responses
Irrigated Crops	Environmental Water
Summer Temperatures	Agricultural Water
Population	Drinking Water
Land-Use	Commercial/Industrial Water
Water Conservation	All Water
Precipitation	

II.C Where We Were and Where We Are Going

Where We Were:

The 2009 Water Plan Update included a brief discussion of using indicators to understand water-related conditions in California and how management could be improved to make water management more sustainable. In early 2010, California Water Plan's work team initiated the development of the envisioned California Water Sustainability Indicators Framework. Through a series of internal discussions over a period of several months in 2010, the work team developed a project charter for the Framework. Further discussions were held with the Sustainable Water Resources Roundtable, the Bay Institute, the Delta Stewardship Council, and the Strategic Growth Council during 2010 and 2011. Based on these discussions, the project charter was revised accordingly.

As part of Water Plan's outreach process, the project vision, objective, and deliverables were introduced to the State Agency Steering Committee, the Public Advisory Committee, and the Tribal Advisory Committee. Based on their feedback, the project charter was further revised.

In early 2011, DWR engaged UC Davis to provide technical support to the project to assist in the development of the Framework, based upon earlier indicator system development by UC Davis in 3 regions of California (Shilling et al., 2010 & 2011; Antos et al., 2011). During the same time, USEPA Region 9 initiated and finalized discussions with DWR to collaborate in the project through financial and advisory support.

Where we are going in Phase II:

The Framework is basically in development until the Water Plan Update 2013 is finalized. Until then, it will undergo periodic review by the Water Plan Sustainability Indicators Workgroup with interagency participation, the Public and Tribal Advisory Committees, and other bodies and individuals.

Meetings and Workshops

The Framework w presented to the Sustainable Water Resources Roundtable (SWRR) in early winter 2011. This was an important presentation and review because the Roundtable represents water agency officials and scientists from throughout the country. The Framework will be introduced in several Water Plan Regional Forums planned in 2012 to incorporate the perspectives of the regional stakeholders. Periodic vetting and discussion of the Framework will complement the Phase II model implementation of the Framework described below. This will be an ongoing process and will continue even after the Framework has been nominally finalized.

Model Implementation of the Framework

The Framework will be implemented in at least one region of California, in order to test its effectiveness as a system before its incorporation into Water Plan Update 2013.

Implementation will involve:

1) Selection of a test region using criteria developed with input from the SWRR. UCD and DWR will consider which region in California best fits the combined needs of modeling implementation of the Framework, an assessment of water sustainability, and partnering with other state and regional organizations.

Work Plan: Using 7 criteria, UCD and DWR staff evaluated 14 candidate regions for their potential role as pilot regions. The criteria were:

a) the region represents a cross-section of the wide range of activities and natural conditions of California;

b) working with the region will assist with regional management needs and meet state-level/Water Plan management needs;

c) medium-quality data is available for a cross-section of indicators;

d) the region has the capacity and desire to engage with the project team;

e) the region has a coastal connection;

f) the area represents a cross-section of the wide range of activities and natural conditions of the region; and

g) the region is a good candidate for regional water footprint analysis.

Using these criteria, the following 5 regions were selected for further evaluation and discussion with regional planners: Santa Ana River watershed, Silicon Valley, Sonoma County, Northern Sacramento Valley Integrated Regional Water Management project, and the San Joaquin Valley Partnership.

2) Interaction with regional stakeholders regarding regional objectives and data sources. The Framework approach is based upon stakeholder goals and objectives, so an early step will be for the UCD team to elicit those goals and objectives from stakeholder agencies and organizations. This step depends on a close partnership and clear communication between the UCD team and regional partners;

3) Indicator selection, indicator data collection and analysis. After discussion with regional stakeholders, indicators will be selected (primarily from the recommended indicators in the Framework). Data will be gathered from local, regional, and state resources corresponding to each of the indicators. The data will be managed so as to allow others to access the data as part of provenance for the indicator evaluation and reporting. Targets will be selected for each indicator, in consultation with regional experts. Each indicator will be evaluated using the distance to target method. In addition, data for the Water Footprint (WF) calculation will be collected from state and regional sources. The WF will be calculated for the state in collaboration with the Pacific Institute, who has already begun such a calculation; and

4) Publication of a water sustainability report for the region. After discussion with regional stakeholders, a reporting mechanism will be selected (e.g., report card) that effectively conveys the findings of the model implementation of the Framework in an understandable format and level of complexity. This implementation of the Framework will include use of the "water footprint" as an important index of water use impact. As a further test of the Framework, a sub-set of indicators will be used at the state-scale. Issues and gaps associated with using the Framework at the region and state scale will be discussed. This combination of Framework testing at the regional and state scales will help to determine how useful the proposed approach will be in implementation of the Water Plan 2013 Update. The UCD team will also develop a proof-of-concept decision support tool for visualizing the data from several EPA-supported projects modeling groundwater, vegetation productivity, the ecological footprint, and the water footprint from the current project.

The combined findings from the Framework development, Phase II will be developed as a report to inform the Water Plan Update 2013.

Finalizing the Framework

The Framework description is anticipated to take its initial shape by the end of 2011. By the end of testing in Phase II, the Framework will be further refined for inclusion in the Water Plan 2013 Update. This will include an assessment of the pilot tests, final recommended set of indicators and analysis approach for regional and state scale uses, and possible mechanisms for reporting.

Coordination with Related Efforts

<u>USEPA:</u> DWR and UC Davis are closely collaborating with USEPA's California Footprint Sustainability Indicators for Decision Support project. The two major components of the project are the development of ecological and water footprints. USEPA has engaged Global Footprint Network to conduct the ecological footprint analysis at the State of California level to compare the population's use of natural resources with the ecosystem's ability to provide those resources. In partnership with USEPA, DWR and UC Davis will lead the development of a water footprint analysis to fill the gap in the ecological footprint methodology. This will involve use of specific sustainability indicators, incorporated into a footprint assessment in a specific region of California.

<u>Strategic Growth Council (SGC):</u> The SGC is an inter-agency collaborative organization, established in 2008, that is intended to support sustainable land, air, and water conditions and community well-being. DWR and UC Davis are coordinating with SGC in order to more closely align the indicator analysis carried out in SGC's regional reports with the Framework. In the first iteration of this coordination, water sustainability indicators may be adopted by the SGC regional reports as the method to measure this aspect of environmental, economic, and

community well-being. In future work, we hope that the methods used in the Framework and the SGC regional reports will become more similar.

Regional Agencies: UC Davis is also working with several local and regional partners and companion efforts to encourage more coordination among similar efforts in California. The Sonoma County Water Agency is interested in partnering with DWR and UC Davis on implementation of the framework in watersheds and counties of the North San Francisco Bay. UC Davis is working with the Sacramento Regional County Sanitation District on developing a water quality report card for the Lower Sacramento River that will be consistent with the Framework.

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Appendix A Extended Glossary of Terms

This appendix provides a list of terms useful in communicating effectively and ensuring consistency among similar sustainability indicator systems [1] The terms and definitions are primarily based upon the work of three regional California Watershed Assessment Framework (CWAF) projects conducted between 2008 and 2011[2]. The CWAF was built to meet watershed monitoring needs and performance measures identified in the California Watershed Management Strategic Action Plan. The terms and definitions originated from a combination of reports and background documents from state, federal, and global efforts towards developing social and ecological condition reporting frameworks for monitoring condition and performance.

Sustainability Indicators Framework

The Sustainability Indicators Framework (SIF) is in an evaluation framework developed for use at the scale of natural or jurisdictional land units. The concept and use of the SIF is partially based upon the CWAF structure and process, which was in turn based upon an approach developed by the USEPA's Science Advisory Board and has been adapted

The framework provides a scientifically defensible approach for aggregating and assessing a variety of environmental, economic and social information. The framework can be used to assist in linking the condition of a study area's natural and social conditions into a broad framework consisting of the sum total of the physical, chemical, social and biological components of the study area and how they interact and change over time. The SIF includes approaches and indicators for evaluating of economic and social conditions and is a way of integrating consideration of environment, economics, and equity/social conditions at natural or jurisdictional scales/extents. The SIF acknowledges that humans and their activities are integral parts of ecosystems and that most human endeavors depend upon healthy natural systems.

Systems

Indicators are usually chosen to represent parts of complex systems. A system, as the term is used here, is a set of interacting parts, where both the components and the relationships among them is part of the system. For example, an ecosystem is composed of interacting organisms and natural processes, social and economic systems are composed of interacting people and organizations/institutions. Typically, economic systems as defined by financial or other material exchanges and conditions, while social systems are the remaining conditions (e.g., health). It is usually important when using this term to define the boundary conditions for the particular application of the term.

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[1] http://www.water.ca.gov/watersheds/framework.cfm

[2] Developed by Fraser Shilling (UC Davis) based on the index/indicator literature and feedback from Jeff Sharp (Napa County) and Mike Antos (Los Angeles San Gabriel Rivers Watershed Council).

Social and Ecological Themes, Domains or Categories

A category is a class of similar concepts, ideas, or things within in an organized and rule-based system to discriminate among classes where the discrimination is based on apparent differences among the categorized objects. Themes and domains are types of category and are terms of art referring to large parts of natural or social systems (e.g., landscape condition). Categories, themes and domains are one way to organize information in an overall condition index, like the SIF, where the categories and sub-categories are used to classify related indicators (figure 1). The 8 essential attributes identified in the CWAF valuation projects is a means to categorize various attributes that describe a watershed and are described below.

Figure 1 Indicators nested within sub-domains, in turn nested within domains

Landscape Condition The extent, composition, and pattern or structure of (non-human) habitats in a landscape.
Biotic Condition The condition or viability of communities, populations, and individual biota (i.e., at the scale of individual habitat types).
Ecological Processes Metabolic function of ecosystems - energy flow, element cycling, and the production, consumption, and decomposition of organic matter at the ecosystem or landscape level.
Social Condition The examination of the organization and development of human social life within the watershed, including measurements of community and social patterns, and behavior of individuals and groups.
Economic Condition Measures of the production, distribution, and consumption of goods and services within a watershed, including the valuation and of non-market resources that provide individual and community utility.
Chemical and Physical Characteristics Physical parameters and concentrations of chemical substances present in the environment/watershed (water, air, soil, sediment).
Hydrology/Geomorphology Characteristics that reflect the dynamic interplay of surface and groundwater flows and the land forms within the watershed.
Natural Disturbance The historical and/or contemporary function of discrete and usually recurrent disturbances, which may be physical, chemical, or biological in nature, that shape watershed ecosystems.

Goals & Objectives

"***Goals and Objectives****. Ideally, environmental management programs begin with a process to develop goals and objectives that articulate the desired ecosystem conditions that will result from the program(s)*." (USEPA SAB Report)

Goals describe desired outcomes for a watershed or other natural or social system, through a particular project or program in a stated timeframe. In the case of the SIF, goals are described in the CWP, relating to the desired outcomes for the study area in some stated timeframe.

Objectives are the tactics to the goals' strategies. They describe actions that can be taken to implement or reach goals and are often nested within goals (figure 2). Objectives for systems can be defined as actions that help reach desired outcomes for particular aspects of the system's condition.

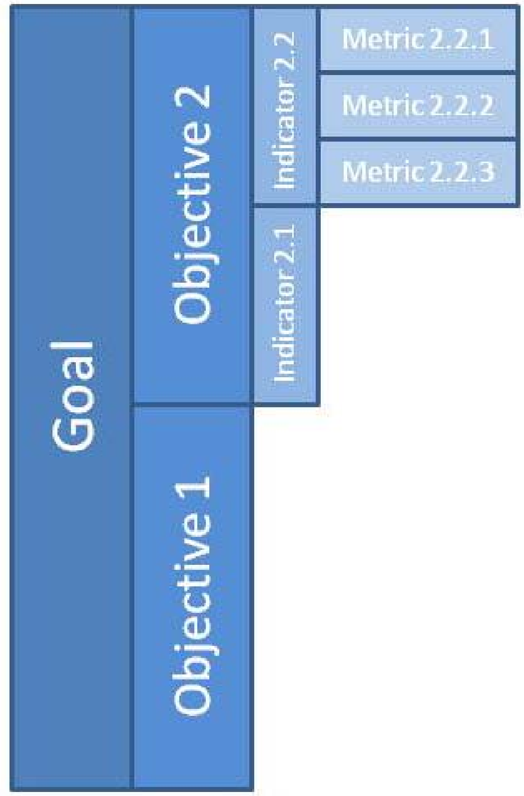


Figure 2 Nested metrics, indicators, and objectives within goals

Index

Sometimes organizations want to develop a comprehensive understanding of environmental or social health and express that as a single score, which is a composite of several or many indicators. This composite is usually called an index. In terms of the SIF, you could imagine scores for indicators within a domain called "water quality" being composited into an overall attribute score for water quality. In this case, the domain is functioning as an index. The SIF is also an index, composed of the component indicators nested within goals and/or objectives, though a single index score for the SIF may be only generally meaningful.

Indicators

"Ecological Indicators *(also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems. Multiple indicators may be associated with each subcategory in the EEA [essential ecological attribute] hierarchy.*" (USEPA SAB Report)

Indicators (the backbone of the SIF process) provide a way to collect information about a condition and to report and compare condition over time. Indicators in the SIF are organized within goals, objectives (figure 2), and domains (figure 1) and are based on metrics or measures of condition. Sometimes indicators and metrics are the same thing. For example, "surface water temperature" is a metric, something directly measured in nature, and also considered an indicator., In contrast, “fish population” is an indicator and may be measured using any of several possible metrics (e.g., number of returning spawning adults).

Metrics/measures

“***Measures.*** *The measures are the specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators*.” (USEPA SAB Report) Metrics/Measures are the building blocks of indicators and thus the foundation of a condition assessment system. Examples of metrics and measures include dissolved oxygen concentration, proportion of successful nests (i.e., produce young) per season for a particular riparian bird species, and fire return interval for a particular plant community within a study area. Each of these measures might fit into an indicator composed of one or more metrics (e.g., “fire dynamics”) that in turn is categorized into a system domain (e.g., natural disturbance) or goal.

Variance and Confidence

The degree of certainty in the Report Card results depends on two conceptual questions: whether good indicators were chosen and how well the data presented for each indicator accurately reflect the real status or trend in the metric(s). The first of these questions pertains to the indicators themselves and how well they address the objectives or attributes they are meant to represent. Certainty about the indicators depends on four main factors: Importance, understanding, rigor, and feasibility.
»»Importance — the degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome,
»»Understanding — the degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s),
»»Rigor — the degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested or confounded by other information, and
»»Feasibility — the degree to which input data necessary to calculate the proposed performance measure can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.

The second question pertains to statistical confidence in the data presented for each indicator. The available data may contain a variety of sources of uncertainty including: measurement error, uncertain or inappropriate use of the sampling frame, sampling error, and process error. »»Measurement error. Random or systematic errors introduced during the measurement process, sample handling, recording, sample preparation, sample analysis, data reduction, transmission and storage (USEPA 2006; Thompson 2002)
»»Uncertain/inappropriate interpretation of sampling frame. Errors in inference resulting from opportunistically mining the available data without knowledge of the sampling frame1. For example, macro-invertebrate data may have been collected by several different studies with different objectives and target populations (e.g. they could have focused on

different stream orders). Without this knowledge, we must make assumptions about the probability of selecting each site and the appropriate weighting of the observation.
»»Sampling error. The error resulting from only examining a portion of the total population (Cochran 1977; Lohr 1999; Thompson 2002), if a census of the population is taken (e.g., school lunch enrolment) then there is no sampling error.
»»Process error. Actual variability between spatial or temporal units in the population. This source of variability exists even if a census is taken with no measurement error. This is often referred to as natural variability.

Any of the above sources of uncertainty affects confidence in the estimates of status and reduces the ability to detect trends over time. For some indicators quantification of different sources of uncertainty in the data may be possible, but in many cases there are limitations to providing a qualitative description of the likely sources of error and associated magnitude. Reporting confidence, certainty, and/or variance is important to building trust for the indicators framework.

Distance to Target

Comparing indicator-parameter values to a reference or target condition is a critical step in the Framework. It is where sustainability meaning is attached to the data. There are a variety of ways to measure and normalize measurement of parameter conditions to target or reference conditions.

The table below summarizes the main methods, their advantages and disadvantages.

<table>
<tr><th colspan="2">Method</th></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td colspan="2">Empirical normalization
Min max method gives the 0 value (Min) to the most unfavorable observed value and 1 or 10 (Max) to the best recorded value. All intermediary values are calculated based on the formula: $Y = X - Min/(Max - Min)$.</td></tr>
<tr><td>Simple and efficient to compare alternatives with an initial state</td><td>Variability of Min and Max values that depend on observed values, new observation outside the previous limits will lead to new normalization. Extreme values/or outliers could distort the transformed indicator</td></tr>
<tr><td colspan="2">Axiological normalization
Close to the empirical approach with min and max limits. The limits are not statistically identified, being chosen based on the undesirable situation, which receives the “0” value, and on the ideal situation, which can or cannot correspond to a strategic objective and which receives the value “1”.
Alternatives to min and max here are :
distance to a reference method that takes the ratios of the indicator to a value of mean reference for this indicator: $Y=X/X_{expected}$
Indicators above or below the mean : this transformation considers the</td></tr>
</table>

indicators which are above and below an arbitrarily defined threshold, *p*, around the mean $X_{expected}$: $$Y = \begin{cases} 1 \text{ if } \frac{X}{X_{expected}} > (1+p) \\ 0 \text{ if } (1-p) < \frac{X}{X_{expected}} < (1+p) \\ -1 \text{ if } \frac{X}{X_{expected}} < (1-p) \end{cases}$$	
Simple and efficient to compare alternatives. Reduced impact of extreme values	Might be less realistic than the empirical approach because limits depend on objectives, not on observations
Mathematical normalization Transformation of data by means of a mathematic function in order for the values to range between an upper and a lower limit	
	Lack of transparency for the user and possible change of initial distribution of values
Statistical normalization All values are expressed in standard deviation, so that the variables average is equal to zero	
Does not depend on min and max values determined by strategic objectives or statistics	Does not depend on min and max values determined by strategic objectives or statistics

This measurement of distance to a target or reference condition is sometimes called the "ideal point" method (Malczewski, 1999). The ideal point method was first introduced in the late 1950s and expanded by Milan Zeleny in the 1970s (Pomerol and Barba-Romero 2000). Zeleny (1982) described the measurement of closeness with: *di = fi* – fi (xji)* where *di* is the distance of attribute state *xji* to the ideal value *fi**, i indicates the attribute and j indicates the objective.

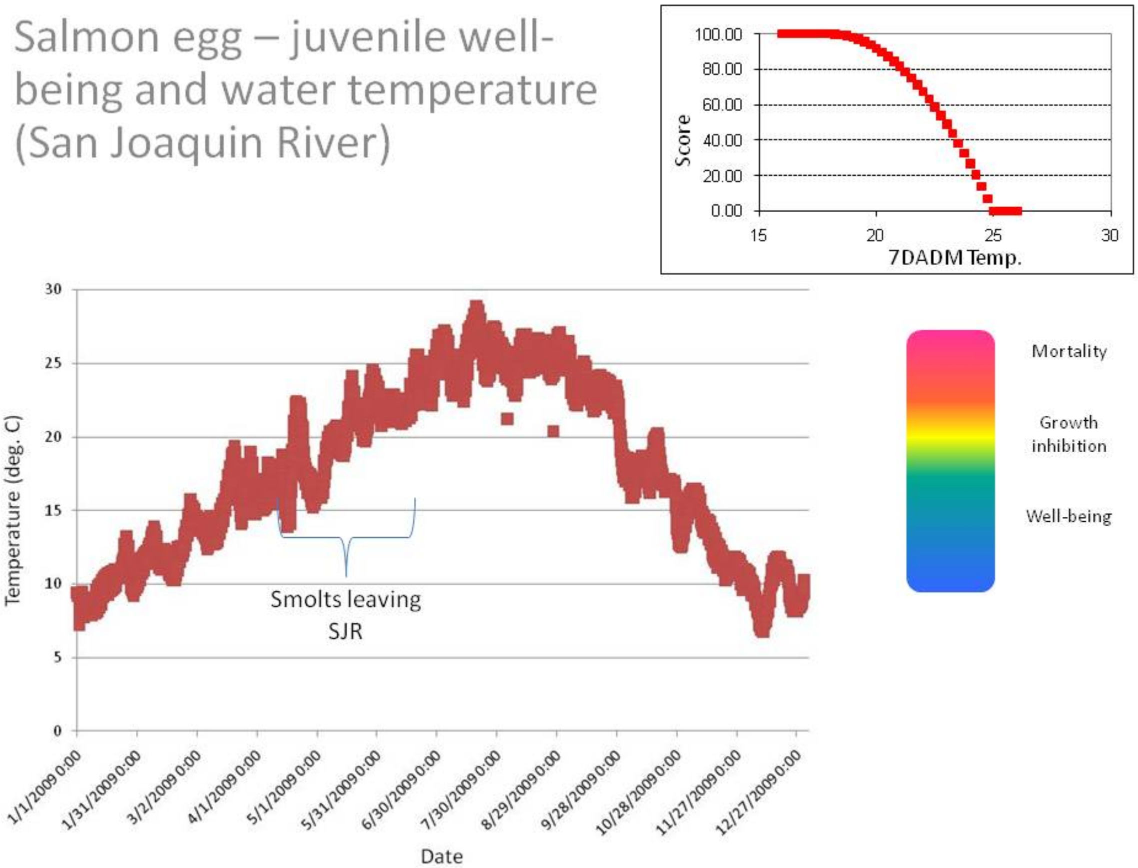


Figure 2. Comparison of salmonid young well-being to San Joaquin River water temperature. Inset graph: relationship between temperature and score for water temperature, based upon temperature sensitivity of salmonid young.

Appendix B Indicator Selection Criteria

Availability of high-quality data

One of the main obstacles many face when selecting indicators is the lack of available data. Frequently the data for an indicator that may be important are not available. Alternatively, the data might only be available for random points in time or for limited geographical areas. The data might have been collected for one purpose in a particular way that served the original purpose, but for your purposes, it may be inadequate. If new data are needed, the feasibility of collecting them might be limited by the amount of effort required to accurately make the measurement (e.g., actual salmon escapement). Alternate indicators may be considered that have significantly lower cost (e.g., remote-sensing based habitat assessment). For certain indicators, it may be very cost-effective to collect the required metrics (e.g., habitat assessment for a species of concern), but the indicator may not represent the process of concern compared to more expensive indicators (e.g., actual population trends in the species of concern). Data collection and analysis costs (further described as a separate criterion below) have to be evaluated in relation to the potential cost and societal implications of a proposed action or inaction, i.e., the greater the expected tradeoffs between societal goals, the greater the need for certainty in the environmental outcome. When choosing indicators, it is essential to carefully consider the current availability of data for the indicator, as well as how much data will be available in the future from our own collection and from the efforts of others. The availability of metadata is one criterion for selection of particular data for corresponding indicators. Finally, indicators will be useful and useable in the long-run if there is a process for updating the corresponding database, metadata, and data collection & QA/QC procedures.

Long-term data affordability

One factor to consider in evaluating indicators is the costs associated with collecting and analyzing data. One consideration in evaluation the costs and benefits is the usefulness of the information for evaluation of management and ecosystem condition. Indicators that are cost-effective, while accurately representing ecosystem characteristics are preferable. The primary guide is that the amount of data required to adequately report on condition and change in condition can be and are being collected with the resources available. The data should also be collected in a standardized way for which there are QA/QC procedures described. For critical indicators (those reflecting important system conditions for which there is no viable alternative), more resources may need to be made available if they are currently inadequate.

System representation

Another factor to consider in indicator selection is how well the indicator reflects the issue for which it was selected. Frequently, certain indicators are widely recognized to be a useful measure for an issue. Selecting these indicators is usually a 'safe bet'. For example, percent riparian canopy cover is considered a good indicator of riparian conditions because it has been extensively studied and shown to have a good relationship with stream temperature and the detection of changes can be made easily. Selecting indicators that have been carefully evaluated for their scientific validity means they usually have wider acceptance than those that haven't been studied very much, and they are more likely to allow you to make confident inferences about system condition. Indicators that are representative of large aspects of system condition and trends are preferable for those that have narrower utility, all else being equal. Sometimes the condition is itself an important ecosystem driver. For example, surface water temperature is an important ecological variable for understanding the condition of aquatic ecosystems. It is also the target of management actions to benefit these ecosystems, which is another criterion described below. Indicators that can provide important information at both broad and fine spatial scales are likely to be more useful as they can help inform both strategic and site-specific decisions.

Sensitivity to change over time

The ability to report on trends over time is a key function of an indicator. The availability of a data set collected over a period of many years is ideal. Indicators that respond relatively quickly to management intervention and can effectively be used to measure change over time may be preferable to those that require data over long periods of time to observe changes due to management actions. This is especially useful in reference to short-term grants and contracts, or short-term program evaluation, which require performance measures to demonstrate the success or failure of the project. If possible, select indicators whose range of natural variation can be quantified and that permit change detection over short periods of time (2-3 years). At the same time, recognize that many of the processes that we try to improve with restoration programs take decades or longer to change or recover (e.g., salmon population recovery). Indicators for these projects and programs should be stable over these longer timeframes (i.e., decades).

Independence of indicators from one another

Independence refers to how related indicators are to each other. Road density and %impervious surface are related indicators because roads are often impervious. Indicators that are relatively independent are preferable (e.g., rate of ground water use for irrigation and migration barriers), while recognizing that some critical indicators are related and somewhat dependent on each other (e.g., surface water temperature, flow, stream shading, hydraulic connectivity to groundwater, salmon rearing habitat suitability). The concern about independence is important for designing efficient indicator systems, but is secondary to choosing easily-measured and representative indicators. You may choose related indicators, but you would be constrained in your attempts to use them together to explain condition of a system. For example, if (a) surface water temperature, (b) flow, (c) stream shading, (d) amount of groundwater withdrawal, and (e) salmon rearing habitat were indicators of success for a restoration program, then you could not report changes in these indicators without acknowledging that (a) depends on (b), (c), and (d); (e) depends on (a), (b), (c), and possible indirectly on (d) through (b); and (c) may depend on (b) and (d). If restoration of riparian shade (c) was a goal in order to benefit salmon rearing (e), then the inter-dependence of some of the other parameters would need to be acknowledged and potentially controlled-for in order to measure the true effect of increased riparian shade on salmon rearing.

Supports management decisions and actions

Measuring conditions in the environment and in communities can inform policy development and social/fiscal investments. Indicators should be informative in evaluating environmental/social/economic conditions, as well as the influences on these conditions. Another useful characteristics of indicators is that they can be used to evaluate the effects or effectiveness of management actions — be it a state or federal agency or the goals and objectives of a watershed council. Whatever the business of the organization is, indicators should provide information that can be used to assess the effectiveness of the work and efforts of the group. In the past, *activities* were seen as a measure of the effectiveness of an organization. The number of grants awarded, the number of pamphlets distributed, or similar "bean counting" has been used extensively to evaluate an organization's productivity. Performance measures, on the other hand, look at the environmental and social *outcomes* of these activities to determine an organization's effectiveness. This is the reason it is so important to select indicators that are closely linked to management actions and decisions and that can be reported and understood in public arenas. The point of most indicators is to inform a wide audience about conditions in the environment and communities. Indicators should be science-based and easily understood by various kinds of decision-makers (e.g., scientists, public, elected officials). They should be equally presentable in summary form in newspapers and on web sites. Finally, indicators should be based upon reportable technical & scientific information and links easily made between summary presentations and the source data and knowledge.

Appendix C Indicator Systems from Around the Globe

Learning from Other Efforts in California and the US

The Water Sustainability Indicators Framework will not be developed in isolation. We intend to benefit from the lessons learned from other similar efforts described below.

Since 2002, the Sustainable Water Resources Roundtable has brought together State, federal, corporate, nonprofit, and academic sectors to advance understanding of the nation's water resources and to help develop tools for understanding and ensuring their sustainability (acwi.gov/swrr/index.html). SWRR has developed a five part framework with a set of 14 key sustainability indicators that can be useful for other entities developing their own indicators.

The Sacramento River Watershed Program beginning in 1996 developed the Sacramento River Watershed Management Plan that included a Roadmap and Watershed Health Indicators Program. The Roadmap provides an overview of the basin's six subregions and a picture of watershed health within the Sacramento River Basin. The Watershed Health Indicators Program uses the Watershed Assessment Framework to better understand some of the relationships between social, economic, and environmental conditions, and watershed management actions. The Watershed Health Indicators Program Report Card effort was launched in 2008, focusing on the Feather River Watershed for tracking watershed conditions and trends.

The Bay Institute Ecological Score Card was first produced in 2003 and then updated in 2005; another update is anticipated in 2013. In 2005 update, more than three dozen science-based indicators have been used to grade the condition of the Bay region. These indicators were combined into eight indexes. The score card system compares current conditions in the Bay and its watershed to: historical conditions, environmental and public health standards, and restoration targets.

State of the Great Lakes 2009, an undertaking by the U.S. EPA and Environment Canada, used Environmental Indicators for assessing status and trends of the Great Lakes Ecosystem (Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario). The status of ecosystem components was assessed in relation to desired conditions or ecosystem objectives. The effort assessed 62 ecosystem indicators categorized into 8 different groups.

2010 Environmental Performance Index (EPI) was prepared by the Center for International Earth Science Information Network (CIESIN) at Columbia University. The effort ranks 163 countries on 25 performance indicators, tracked across 10 policy categories covering both environmental public health and ecosystem vitality.

Framework name	Project URL	Complete report URL	Date	Institutional lead	Constituents
An Indicator Framework for Linking Historic Preservation and Community Economic Development		http://www.springerlink.com/content/j3t4186157728877/fulltext.pdf	Mar 29 2011	Arizona State University School of Community Resources & Development	
Sustainable Industries Performance Indicator Framework	http://www.ecoindustrial.ca/usgbc_toolkit/	http://www.ecoindustrial.ca/usgbc_toolkit/SustainableIndustryIndicatorsFinalReport23Mar05_protected.pdf	Mar 23, 2005	Industry Canada's Sustainable Technologies and Service Industries	
Framework for Measuring Sustainable Development in Catchment Systems	http://planet.uwc.ac.za	http://planet.uwc.ac.za/nisl/Gwen%27s%20Files/GeoCourse/Integrated%20Environmental%20Management/IEM/Peer%20Reviewed/Walmsley2002.pdf	2002	Mzuir Consultants, South Africa	
Transport Monitoring Indicator Framework	http://www.transport.govt.nz/ourwork/tmif/	http://www.transport.govt.nz/ourwork/TMIF/Documents/TMIFV2%20FINAL.pdf	2009	Ministry of Transport, New Zealand	
Food Security Indicators and Framework for Use in the Monitoring and Evaluation of Food Aid	www.fantaproject.org	http://www.fantaproject.org/downloads/pdfs/fsindctr.PDF	Jan 1999	US Aid	

Programs					
Framework to evaluate ecological and social outcomes of collaborative management: lessons from implementation with a northern Arizona collaborative group.		http://www.springerlink.com/content/2u4lk31q6558uu28/fulltext.pdf		School of Sustainability, Arizona State University	
JSEM: A Framework for Identifying and Evaluating Indicators		http://www.springerlink.com/content/p36j1x36832834pl/fulltext.pdf	Dec 1998	Dynamic Corp Environmental Servces, US EPA, Corvallis OR	
A quantitative indicator framework for stand level evaluation and monitoring of environmentally sustainable forest management		http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6W87-50SJMGB-1-6&_cdi=6647&_user=4421&_pii=S1470160X1000124X&_origin=gateway&_coverDate=03%2F31%2F2011&_sk=999889997&view=c&wchp=dGLbVtz-zSkWA&md5=7bc9184b665e83a1c156a9a97593a610&ie=/sdarticle.pdf	13 Nov 2009	Ghent University (lead author)	

Biodiversity Indicators Partnership	http://www.bipindicators.net/	http://www.bipindicators.net/LinkClick.aspx?fileticket=NYhSvmOUgps%3d&tabid=155	2010	BIP	
Puget Sound Partnership	http://www.psp.wa.gov/	http://www.psp.wa.gov/downloads/SP2009/IndicatorSummaryReport(Final)120108.doc http://www.psp.wa.gov/downloads/SP2009/IndicatorEvaluationSpreadsheet091308.xls	2008	PSP	
Sustainable Water Resources Roundtable	http://acwi.gov/index.html	http://acwi.gov/acwi2008/slide.lib/SWRR-Indicators-Feb05Draft-Part1and2combined_new.pdf	2008	Advisory Committee on Water Information	
Coastal Institute	http://www.ci.uri.edu/	http://www.ci.uri.edu/Projects/PNB/Chafee-HUD/Indicators_Final.pdf	2003	CI – Narragansett Bay Region	
New Hampshire Forest Resources Plan Revision	http://www.na.fs.fed.us/	http://www.na.fs.fed.us/sustainability/pubs/criteria/lessons_learned.pdf	August 2006	USDA – Forest Service	
An adaptive indicator framework for monitoring regional		http://sspp.proquest.com/archives/vol6iss1/0901-004.vanzeijl.pdf	June 2, 2010	Maastricht University, The	

sustainable development: a case study of the INSURE project in Limburg, The Netherlands				Netherlands	
European Environment Agency	http://www.eea.europa.eu/	http://www.google.com/url?sa=t&source=web&cd=117&ved=0CD8QFjAGOG4&url=http%3A%2F%2Fwww.eea.europa.eu%2Fen%2Fpublications%2Ftopic_report_2003_1%2FTopic_1_2003_web.pdf&rct=j&q=indicator%20framework%20water&ei=-kunTaihBYK2sAOs3Kn6DA&usg=AFQjCNFVjxl-s4ADH841VPGij4E5aXoKAA&cad=rja	2003	The EU	
An Indicator System for Surface Water Quality in River Basins		http://repositorium.sdum.uminho.pt/bitstream/1822/4638/1/OLIVEIRA_CI1_2005.pdf	2005	Universidade do Minho, Portugal	Good to read to get sense of how to develop indicators
UN Indicators of sustainable development: framework and		2007 version (last one) http://www.uneca.org/eca_programmes/sdd/events/Rio20/WorkshopSDIndicat	2007	UN	1. Categories, indicators, methodology, evaluation per country,

methodologies 2001, 2007		or/SustainableDevelopmentIndicators.pdf 2001 version http://www.un.org/esa/sustdev/csd/csd9_indi_bp3.pdf	 April 2001		recommendations. 2. Application at national level 3. Discussion of different type of frameworks 4. Topics: health, poverty, governance, education, demographics, natural hazards, land, freshwater, atmosphere, ocean and coasts, biodiversity, economic development, global partnership, consumption and production patterns 5. Currently applying the new version in Africa
	UN Sustainable indicators for Africa	http://www.uneca.org/eca_programmes/sdd/events/Rio20/Workshop-Institutional-StrategicFrameworks/MerseiEjiguSDIndicatorsFrameworkforAfrica.pdf	2011	UN	Draft version for discussion
Indicator Frameworks for Assessing Irrigation		http://www.clw.csiro.au/publications/technical2005/	2005	CSIRO – Australian	1. Include sustainability indicators based on

Sustainability		tr1-05.pdf		Research Institute	system elements, system attributes and on a range of spatial scales 2. Presents different indicator frameworks for selection (i.e. state and control, driving force state response, TIM, AMOEBA) 3. Assess criteria for framework selection and assess frameworks
Water policy and reform framework in Australia	http://www.environment.gov.au/water/australia/coag.html National Water Quality Management Strategy http://www.environment.gov.au/water/publications/quality/index.html http://www.environment.gov.au/water/publications/environment	** Most of the document links do not work in the main webpage http://www.environment.gov.au/water/publications/quality/pubs/water-quality-framework.pdf	2002	Australian government	1. Different documents of principles, guidelines, objectives for water quality management. Some of them are more specific sub-frameworks with measures 2. Main topics: fresh and marine water, groundwater, diffuse and point sources, sewerage system, effluent management, water recycling

	al/index.html	http://www.environment.gov.au/water/publications/action/pubs/cehw-framework.pdf	2009		3. Water use prioritization framework, cooperative use
A National Framework for Improved Groundwater Management in Australia		http://www.environment.gov.au/water/publications/environmental/groundwater/pubs/framework-groundwater.pdf	1996	Australian government	Includes the main topics and indirectly presents indicators that should be defined for groundwater management
Conceptual Framework to Develop and Use Water Indicators		http://siteresources.worldbank.org/INTEEI/811099-1115809852605/20486439/ConceptualFrameworktoDevelopandUseWaterIndicators1999.pdf	1999	CIAT Colombia	Water indicators developed for two approaches: a project-based approach, and a Pressure-State-Impact-Response approach
Water framework directive (this is the framework for the whole EU)	http://www.water.org.uk/home/policy/water-framework-directive/about-wfd http://www.water.org.uk/home/policy/water-framework-directive	http://www.water.org.uk/home/news/press-releases/sustainability-indicators-09-	2006 - 2010	UK	1. Webpage: aims, objective, strategy, timetable, milestones (However no specific pdfs of the framework itself) 2. Water sustainable indicator report for the

	http://www.doeni.gov.uk/niea/water-home/wfd.htm http://www.legislation.gov.uk/uksi/2003/3242/contents/made	10/sustainability-2010-final.pdf http://www.doeni.gov.uk/niea/ams-report.pdf			UK
Swiss sustainable indicator system	http://www.bfs.admin.ch/bfs/portal/en/index/themen/21.html	http://inderscience.metapress.com/media/m3pnwhtyvral7xxuueet/contributions/x/k/0/5/xk0583543t853h57.pdf	2007	Switzerland	A paper that describes how the system was built, the development processes, selection of indicators and critical assessment
Minnesota Water Sustainability Framework	http://wrc.umn.edu/watersustainabilityframework/index.htm	http://wrc.umn.edu/prod/groups/cfans/@pub/@cfans/@wrc/documents/asset/cfans_asset_292471.pdf	2011	USA, University of Minnesota Water Resources center	Complete framework document, including environmental, social and economic components. Vision, objectives, Strategy, Outcomes, Measures of Success, and Benchmarks
Ecosystem Services Indicator Framework		http://www.esindicators.org/files/esid/Framework%20discussion%20for%20download.pdf			
Sacramento River Basin Report Card & Technical	http://ice.ucdavis.edu/waf/	http://ice.ucdavis.edu/waf/sites/ice.ucdavis.edu.waf/	2010	Sacramento River	Environmental Indicators for the

Report		files/WHIP_TechRep_2010_0.pdf		Watershed Program(SRWP)	Feather River Watershed
The State of the Great Central Valley of California Indicator Series	http://www.greatvalley.org/indicators/index.aspx	Multiple, see URL link	Ongoing, last in 2009	Great Valley Center	Economy, Environment, Community Well-Being, Public Health Access, and Education and Youth Preparedness.
State of the Sound	http://www.psp.wa.gov/	http://www.psp.wa.gov/downloads/SOS09/09-04534-000_State_of_the_Sound-1.pdf	2009	Puget Sound Partnership	Various ecological and human health indicators.
The Index of Sustainable Economic Welfare	http://www.econ-pol.unisi.it/dipartimento/it/node/296	http://www.econ-pol.unisi.it/quaderni/449.pdf	2005	Università degli Studi di Siena, Italy	Economic evaluation like "gross domestic product"
Health-e-Waterways	http://www.health-e-waterways.org/		2009	University of Queenslands	environmental indicators (watersheds)
Chesapeake EcoCheck	http://www.eco-check.org/		2011	NOAA	Mostly environmental (water quality) indicators
Delta Stewardship Council – Fifth Staff Draft Delta Plan			2011	Delta Stewardship Council	Water supply, water quality, and ecosystem condition measures

related to the topic of sustainable water management but there were no detailed frameworks.

EUWARENESS - research project on European Water Regimes and the	http://www.euwareness.nl/home/	http://www.euwareness.nl/methodology/Applied%20methodology.pdf		EU Commission University of	1. Methodology and case studies 2. Scientific and social

Notion of a Sustainable Status		http://www.euwareness.nl/methodology/Scientific%20and%20socio-economic%20objectives.pdf http://www.euwareness.nl/summary/Background%20of%20the%20EUWARENESS-project.pdf		Twente in the Netherlands.	objectives
B-Sustainable is a project of Sustainable Seattle	http://www.b-sustainable.org/about-the-b-sustainable-project	http://www.b-sustainable.org/about-the-indicators-framework	Started 1993, continuously updated	Sustainable Seattle	1. A webpage including the history, development and indicators for natural, built, social, personal environment goals

Appendix D Draft Sustainability Indicators

The following table lists 86 sustainability indicators corresponding to each of the 8 sustainability goals and objectives. To select indicators, 42 sustainability indicator systems (Appendix C) containing >1,800 indicators were reviewed for their potential use in this Framework. These are not the final indicators, a set which will be developed through the coming year of stakeholder review and input. Objectives may imply certain indicators for which indicators have not yet been selected. Indicators in *italics* are candidate “leading” indicators – those useful for projecting and understanding potential future conditions.

Table 1. Proposed goals, objectives, and indicators

California Water Sustainability Indicators Framework	
Sustainability Goal and Objective	**Candidate Indicators (potential leading indicators are in italics)**
Goal 1: Manage and make decisions about water in a way that integrates water availability, environmental conditions, and community well-being for future generations.	
	Percent likelihood per year, over the next 20 years, of water shortage, calculated using 1) up-to-date, climate-sensitive forecasts of precipitation, evapotranspiration, and stream-flow and 2) all water uses, including environmental uses such as in-stream flows and reversing over-drafted basins, and required uses such as treaty-obligated water
	Number of basins with years-long aquifer declines (known as overdraft) or projected future declines
	Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater
	Number of people whose drinking water supply is unhealthy

	Equitable distribution of economic and health benefits from water management
	Total agricultural, residential, and commercial water demand, i.e. demand for all uses other than environmental needs and basic human drinking water requirements
	Drought resilience: the maximum severity of drought during which core water demands can still be met, including social and environmental minimum requirements
	Flood resilience: the maximum flood that can be experienced without exceeding some amount (e.g., $10 million) in damages
	Earthquake resilience: the maximum earthquake intensity that can occur without causing more than some amount (e.g., $20 million) in damages due to water infrastructure disruptions, including levees
	Storm resilience: the maximum storm intensity that can occur without causing more than some amount (e.g., $10 million) in damages due to water infrastructure disruptions, including levees and floods
	Equitable decision-making process for water management, diversity of participating organizations
Goal 2. Improve water supply reliability to meet human needs, reduce energy demand, and restore and maintain aquatic ecosystems and processes. Objectives: Improve water use efficiency; Increase water recycling; and Increase water conservation.	
	Energy required per unit of clean water sourced, treated, delivered, used, and again treated
	Water-miles, distance traveled by units of water used
	Percent of drinking water suppliers which have instituted an affordable "lifeline" rate for low-income residential customers
	Water use per year inside the home per capita, 20% reduction by 2020 (per state law)
	Residential outdoor water use per year per capita, 20% reduction by 2020 (per state law)

	Volume of water re-used (same volume can count more than once) as a fraction of total water used, including onsite, recycled at a plant
	Sufficient flows and timing of flows for maintaining historically-present native fish
	Magnitude and timing of managed system flows suitable for native riparian habitats and geomorphic processes
Goal 3. Contribute to social and ecological beneficial uses and reduce impacts associated with inter-basin water transfers and to the Delta. Objectives: Improve regional water movement operations and efficiency; Investigate new water technologies; Protect ecosystem services and benefits provided by intact and naturally-functioning Delta	
	Hydrological Regime & Physical Structure
	Flow pattern variability /alteration (both important seasonally and annually)
	Stream bank stability
	Channel alteration (artificial change)
	Water Quality
	Water quality index (Surface & Groundwater)
	Ecological Condition
	Relative abundance trend of key indicator species at different life stages (i.e. Delta smelt, Longfin smelt, juvenile striped bass, Chinook salmon, all salmonid populations)
	Relative abundance trend of key non-native species (e.g. Brazilian waterweed (Egeria densa) and water hyacinth (Eichhornia crassipes)), and harmful invasive species (Microcystis aeruginosa (HAB- harmful algal blooms)
	Mercury in fish tissue

	Riparian buffer
	Trophic State Index
	Index of Biotic Integrity
	Sufficient and adequate direction of flows for maintaining historically-present native fish
	Aquatic fragmentation in a watershed or aquatic region
	Percent impervious area within 200 m, or Inverse-distance-weighted impervious cover
	Water Supply
	Water miles; Distance traveled for units of drinking and irrigation water
	Amount of Delta water used by sector (urban, agriculture, municipal, industrial) per season and per year
	Percentage of state and regional water supplied by the Delta
	Use of recycled water as a percent of total water used in the Delta region
	Agriculture
	Rate of Fertilizer Applied (kg/ha)
	% of irrigated lands that meet water quality standards in Delta Region
	Investment in agricultural improvement for water management and quality in Delta region
	Land subsidence (absolute amount and rate)
	Greenhouse gas emissions
	Other uses/services (Recreation, Fisheries, Industry, Transportation)
	Trend in recreational use index in the Delta region
	Industrial production dependant on Delta water/region per year

	Subsistence fishing use in the Delta
	Social and Economic Impacts of Transfers
	Job-equivalents per unit of water transferred from a source region (e.g., agricultural labor force)
	Fiscal cost and benefit for local economy in water-source region due to water transfer
	Equitability of benefit realization for local economies in water-source and water-receiving regions due to water transfer
Goal 4. Increase quantity, quality, and reliability of drinking water, irrigation water, and in-stream flows. Objectives: Increase conjunctive management of new and recycled water from multiple sources.	
	Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater
	Correlation between quality and quantity of available drinking water and household income
	Use of recycled water as a percent of total water used
	Years of average water use represented by the current volume of water stored in available groundwater, reservoirs, imports, expected precipitation, and snowpack
	Proportion of agricultural non-potable water needs--e.g. irrigation--met with non-potable water
	Increase measurable benefit in in-stream flows from water recycling and conservation
Goal 5. Safeguard human and environmental health and secure California water supplies Objectives: Protect and restore surface water and groundwater quality; Protect the natural systems that maintain these services.	
	Quality for Human Use

	Pollutant and bacteria index
	Rate of Fertilizer Applied (kg/ha)
	Tons of industrial pollutants released and disposed of by watershed/region
	Quality for a Healthy Environment
	Mercury in fish tissue
	Periphyton cover and biomass
	Species richness (birds, fish, invertebrates)
	Ratio of observed to expected native species (fish species mainly)
	Flow patterns and alterations
	Surface water quality index
	Groundwater Condition and Rehabilitation
	Groundwater quality index
	Management for Water Quality (salinity, urban-runoff,etc)
	Potential Runoff from Urban Impervious Areas
	Cost of water treatment
	Regional Sustainability for Water Quality
	Water Stress Index
	Water Scarcity Index
	Aquatic ecosystems and processes

	Sufficient flows for maintaining historically-present native fish
	Sufficient flows and timing of managed system flows suitable for native riparian habitats and geomorphic processes
Goal 6. Protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes. Objectives: Practice, promote, improve, and expand environmental stewardship.	
	People's level of support or opposition to environmental regulations (e.g., support for statewide bonds, support for local environmental regulations)
	Number of conservation and restoration projects
	Acres of preservation of existing natural habitats and restoration of degraded habitats
	Number of acres protected or enhanced in aquifer recharge areas
	Forest land conversion: Total acreage over time
	Participation rates in local stewardship by the local stakeholders such as municipalities, indigenous people, irrigation districts, community organizations, watershed associations, conservation groups, and stewardship groups
	The completion of restoration recommendations and key actions during the implementation phase of the process
	Public awareness of source water protection issues
	Proportion of streams monitored at least every 5 years for stream-flow, temperature, fisheries, stability.
	Ecosystems and species under serious risk from unnatural fire frequencies
Goal 7. Integrate flood risk management with other water and land management and restoration activities. Objectives: Improve land-use/cover to reduce flood risk; Improve floodplain-channel	

connections	
	Extent of floodplain restoration and connection between channel and floodplain
	Frequency of levee breaks in the region
	Levee System Integrity Index (stability, risk prevention, maintenance)
	Building standard and/or cost of maintaining levees/assessed value of the land use they protect
	Expected annualized damage for flood risk
	Proportion of watershed covered with impervious surfaces, including pavement, buildings, and turf grass.
	Proportion of floodplain-that is protected from development that is incompatible with flooding
	Cumulative hydrostatic force
Goal 8. Support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water resources management systems. Objectives: Improve and expand monitoring, data management, and analysis	
.	Flow chart of process from data need, collection, analysis, decision-making, implementation, and results
	Process/data needs of local jurisdictions and geographies
	Public reporting system for data and results of analysis as well as methods used
	Standardized methods for data collection and reporting and minimize collection biases
	Data sharing and distribution
	Communication of uncertainty
	Collaboration between scientists and policy makers to understand data and communication needs
	Supports adaptation and resilience to climate change

Description of Candidate Indicators

The 86 indicators below are from table 1 above, organized under each of the 8 sustainability goals & objectives and are examples of indicators appropriate for each objective. The indicators and their component metrics were drawn from existing indicator frameworks that deal with water management, water quality, watersheds, regional sustainability, and ecosystem health. It is a list of indicators so far, not all possible or even best indicators. The indicators are sorted into goals (italics) and each indicator (in bold) is followed by a short description of how the indicator contributes to the objective and measuring sustainability as a whole.

Goal 1: Manage and make decisions about water in a way that integrates water availability, environmental conditions, and community well-being for future generations.

Indicators:

1.A Percent likelihood per year, over the next 20 years, of water shortage
Anticipating water shortages allows for anticipatory management action. This indicator can be annually calculated using 1) up-to-date, climate-sensitive forecasts of precipitation, evapotranspiration, and stream-flow and 2) all water uses, including environmental uses such as in-stream flows and reversing over-drafted basins, and required uses such as treaty-obligated water

1.B Number and estimated capacity of basins with years-long aquifer declines (known as overdraft) or projected future declines
Aquifer water is relied upon to provide consistent water supplies. As these aquifer are overdrafted, future water reliability and uses are impacted. Depending on the depth and geological context of aquifers, they may be rechargeable and available to support future reliable water supplies.

1.C Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater
Drinking water from ground and surface sources is replenished annually to varying degrees, depending on precipitation from the current previous years. If water is withdrawn at a greater rate than it is replenished each year, then a water debt is built up in ground and surface storage reservoirs.

1.D Number of people whose drinking water supply is unhealthy
Californians expect access to clean drinking water. Contaminants may be present in drinking water due to incomplete purification, or contamination during movement of drinking water from source to tap.

1.E Equitable distribution of economic and health benefits from water management
Society expects that public trust resources like water are provided equitably. Although inequity may accrue when water is used in particular businesses, the original supply is expected to be managed and delivered in a way that provides equitable distribution of benefits.

1.F Total agricultural, residential, and commercial water demand, i.e. demand for all uses other than environmental needs and basic human drinking water requirements
The basic water needs of society and the environment may be usefully separated from other demands for water that originate from commercial, industrial, and landscaping uses. Agricultural water demand can be split into the water required to meet the basic caloric requirements of society and the water desired to supply dietary variety (e.g., in meat production).

1.G Drought resilience: the maximum severity of drought during which core water demands can still be met, including social and environmental minimum requirements
Droughts can be measured by precipitation alone (Standardized Precipitation Index, SPI) and by comparing precipitation, evapotranspiration, and runoff (e.g., Palmer Drought Indices). The impact of droughts are a combination of severity and duration. Water needs and demands can be compared with water availability under various drought conditions. National Drought Monitor Web Site: http://droughtmonitor.unl.edu/; NOAA Drought Site: http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html

1.H Flood resilience: the maximum flood that can be experienced without exceeding some amount (e.g., $10 million) in damages
Floods are natural events that rework floodplain and riparian lands, move sediment, and naturally restore ecosystems. They can also impact infrastructure placed in the floodplain. Future flood damage can be estimated based upon the projected extent and severity of floods and the value of infrastructure placed in the floodplain.

1.I Earthquake resilience: the maximum earthquake intensity that can occur without causing more than some amount (e.g., $20 million) in damages due to water infrastructure disruptions, including levees
Levees around the Delta's sunken islands are at risk of failing during an earthquake, leading to salt intrusion into the Delta. Pumps and other infrastructure needed for moving water may also be affected during an earthquake. Risk to these facilities during different earthquake intensities can be estimated and thus indirect effects of damage or loss of the infrastructure.

1.J Storm resilience: the maximum storm intensity that can occur without causing more than some amount (e.g., $10 million) in damages due to water infrastructure disruptions, including levees and floods
There are different ways to measure storm intensity, including the Saffir-Simpson scale for hurricanes and the amount of rain per unit time (e.g., inches/hour). Cumulative

precipitation from intense storms leads to increased risk of flooding. Intense storms are more likely to cause wind and rain damage.

1.K Equitable decision-making process for water management, diversity of participating organizations

A key component to equity and environmental justice is equitable access by all parties to decision-making. This can be measured by evaluating who is part of stakeholder and decision-making processes that affect the distribution, movement, and fate of water.

Goal 2. Improve water supply reliability to meet human needs, reduce energy demand, and restore and maintain aquatic ecosystems and processes. Objectives: Improve water use efficiency; Increase water recycling; and Increase water conservation.

Indicators:

2.A Energy required per unit of clean drinking water delivered

Managing, treating, and delivering water all requires electrical and other forms of energy. This indicator provides a measure of the energy demand associated with providing drinking water. The California Energy Commission and local entities (e.g., Napa County) have been studying the connection between water and energy in order to make both energy and water delivery more efficient and to conserve both.

2.B Distance traveled for units of drinking and irrigation water

Transporting water long distances results in energy, environmental, and water volume costs. Sustainable water management in California is likely to involve greater reliance on local/regional-sourced water. (also in Goal 3)

2.C Percent of drinking water suppliers which have instituted an affordable "lifeline" rate for low-income residential customers

The poorest of California residents may not have the ability to readily pay for drinking water delivered to their home. Water suppliers may supply this public trust resource at a subsidized rate, or for free.

2.D Average water use /household, or /capita, 20% reduction by 2020 (per state law)

Under SB X77, California urban water agencies were instructed to develop a strategy to reduce water consumption 20% by the year 2020. This indicator was used by the Los Angeles San Gabriel Rivers Watershed Council in its recent regional report card project, funded by CALFED/DWR.

2.E Volume of water re-used (same volume can count more than once) as a fraction of total water used, including onsite, or recycled

Re-using water is a useful conservation strategy. Many water districts and other public works agencies are building recycling and re-use infrastructure to reduce the cost and impacts of “new water” use.

2.F Sufficient flows and timing of flows for maintaining historically-present native fish

Native fish, including anadromous species, need in-stream water to complete life-cycles, forage, disperse, seek thermal refuge, and escape predation. These flows must also be at appropriate times of day, year and season to allow them to function naturally. This is a common aquatic ecosystem indicator in managed water systems. (Also in Goal 5)

2.G Magnitude and timing of managed system flows suitable for native riparian habitats and geomorphic processes

Healthy aquatic, riparian, and floodplain ecosystems require periodic high flow events, not just minimum flows. In managed systems, high flows can be provided at appropriate times of year and at frequencies to support dependent systems and processes. Streams and rivers support riparian vegetation, a specialized assemblage of plants that is adapted to and relies upon certain ranges of geomorphic and flow conditions. For example, natural cottonwood tree recruitment occurs when there is a gradual decline in the relative elevation of a river and its associated hyporrheic flow, but not if the decline is too rapid, as can accompany managed systems. Movement and re-distribution of sediment downstream, channel migration, bank erosion, and new land formation are all important functions of in-stream flows. These geomorphic processes are supported above certain flows in a natural system and can be mimicked to some degree in managed systems. This indicator is used in the Sacramento River Riparian Monitoring and Assessment Program, as well as other similar large-river systems. (Also in Goal 5)

Goal 3. Contribute to social and ecological beneficial uses and reduce impacts associated with inter-basin water transfers and to the Delta. Objectives: Improve regional water movement operations and efficiency; Investigate new water technologies; Protect ecosystem services and benefits provided by intact and naturally-functioning Delta

Indicators:

3.A Flow pattern variability /alteration (both important seasonally and annually)

Ecosystems depend on natural flow patterns and variability. High flows are needed to move sediment and re-work riparian and floodplain areas. Many systems may be adapted to the shape of the hydrograph, especially the rate of declining flows, which can dictate germination and success of riparian plants. (Also in Goal 5)

3.B Stream bank stability

Unnatural flow patterns due to water management may cause both increased bank erosion and reduced bank erosion (bank armoring), affecting critical interactions between the bank and the channel.

3.C Channel alteration (artificial change)

Channels naturally fluctuate in the position and relative bed elevation depending on flows, landscape development, and geomorphic processes. Artificially armoring banks, lining channels with concrete, and fixing channels in place can all affect both aquatic and riparian/floodplain ecosystems.

3.D Water quality index (Surface & Groundwater)

This index is a composite of indicators of physical, chemical, biological, and cultural attributes of waterways. The index may be used in both surface and ground-water systems and may vary between these environments. (Also in Goal 5)

3.E Relative abundance trend of key indicator species at different life stages (i.e. Delta smelt, Longfin smelt, juvenile striped bass, Chinook salmon, all salmonid populations)

The well-being of regulated and culturally-important fish species is important to measure in order to understand ecosystem condition, as well as actual and potential regulatory issues associated with water management. Both abundance and trends in abundance can be used.

3.F Relative abundance trend of key non-native species (e.g. Brazilian waterweed (Egeria densa) and water hyacinth (Eichhornia crassipes)), and harmful invasive species (Microcystis aeruginosa (HAB- harmful algal blooms)

Complementary to measuring abundance of native species, is keeping track of non-native, invasive plant species. Under disturbed hydrologic and land-use conditions, non-native aquatic plants can dominate and fundamentally shift ecosystems to new states.

3.G Mercury in fish tissue

This is primarily a legacy effect of mining activities in the 19th century. Mercury in eroded soils and benthic sediments can be methylated under appropriate aquatic environmental conditions and end up bioaccumulated in fish tissue. High enough concentrations are present in many waterways and wetlands to harm piscivorous birds and mammals, including people. (Also in Goal 5)

3.H Riparian buffer

Riparian vegetation naturally extends away from the channel into the floodplain. This habitat type provides habitat for generalist and specialized species, protects banks against excessive erosion, provides woody material to streams, and shades streams, keeping them cool. Proportion of the historic riparian that is currently present is a useful local and regional indicator.

3.I Trophic State Index
This indicator was developed primarily for lakes, but can be used for embayed waters, and is a measure of micro-algal growth. The higher the value, the higher the concentration of algal cells, which can indicate eutrophic conditions.

3.J Index of Biotic Integrity
This is a composite of several indicators of condition and can be applied using metrics for fish, algae, and benthic macroinvertebrates communities. Often metrics of potential impact are included as well (e.g., roadedness). Generally, the higher the value, the more intact the aquatic community.

3.K Sufficient and adequate direction of flows for maintaining historically-present native fish
Native fish are often adapted to certain hydrologic regimes and may not tolerate modified flow patterns or quantities. In estuarine systems, both sufficient water and (bi)directional flow may be important. In stream and river systems, insufficient flows to maintain native fish may occur due to over-subscription of surface and ground water, as well as reduced precipitation from climate change.

3.L Aquatic Fragmentation in a watershed or aquatic region
Streams and rivers may be disconnected by physical and other barriers. Dams, culverts, in-stream impoundments, high temperature, and excessive aquatic plant growth can all separate waterways into segments. Existing fragmentation can be compared to naturally-occurring fragmentation.

3.M Percent impervious area within 200 m, or Inverse-distance-weighted impervious cover
Development of land surfaces can lead to impairment of downhill and downstream aquatic systems. Urban land uses and roads collect rainwater and accelerate delivery of the water to waterways, often overwhelming the flood-control capacities of the waterways. Often chemicals and sediment are conveyed by surface runoff from theses areas.

3.N Water miles; Distance traveled for units of drinking and irrigation water
The long-distance movement of water is one of the most energy-intensive activities in California. Inter-regional water movement may cause social, economic, and environmental harm in the source areas, requires expensive (construction and maintenance) infrastructure, requires constant energy inputs, and puts regional economies at risk that rely on what will inevitably fail.

3.O Amount of Delta water used by sector (urban, agriculture, municipal, industrial) per season and per year

Much of California's water management concern centers around deliveries through and from the Delta and its tributary rivers. Water is not evenly distributed among economic sectors, especially at different times of year.

3.P Percentage of state and regional water supplied by the Delta
Many regions rely on the Delta for their water supply. This dependence may result in liability for conditions in the Delta and risks faced by regions if the Delta water supply was interrupted.

3.Q Use of recycled water as a percent of total water used in the Delta region
Many communities and agricultural operations in the Delta region have high water consumption rates. Surrounded by water, the culture of water conservation and recycled water use in this region does not have the imperative that it does in drier areas of the state.

3.R Rate of Fertilizer Applied (kg/ha)
Application of fertilizers to agricultural fields can impair local and regional waterways, directly and indirectly affecting trophic state, native and non-native plant and animal species, drinking water quality, and bioaccumulation of mercury. (also in Goal 5)

3.S % of irrigated lands that meet water quality standards in Delta Region
Irrigation often results in runoff into local waterways. The runoff may contain fine sediment, agricultural chemicals, and excessive nutrients and dissolved organic carbon.

3.T Investment in agricultural improvement for water management and quality in Delta region
Best management practices can reduce impacts from water consumption and return from agricultural areas. These can include irrigation methods that reduce overall consumption, soil management, cover crops, and agricultural chemical application.

3.U Land Subsidence (absolute and rate)
Farming in the Delta has caused erosion of the peat soils and various levels of subsidence of Delta islands and other areas behind levees. Both the absolute amount that lands have subsided and the rate of change (positive or negative) in subsidence are important measures.

3.V Greenhouse gas emissions
Agricultural activity in Delta landscapes can cause release of soil carbon (as carbon dioxide or methane), contributing to climate change and California's net carbon emissions.

3.W Trend in recreational use index in the Delta region
The Delta waterways are a popular recreation destination for people living both within and outside the Delta region. There are various ways that recreation can be measured

(e.g., number of fishing licenses, visitor days, boating days, camping site occupancy, picnic site occupancy).

3.X Industrial production dependant on Delta water/region per year

Industries rely on a reliable source and amount of water. As industries become more efficient, the amounts and timing of water use and return may decline. Dependence on Delta water may put an industry at risk in the event of catastrophic failure.

3.Y Subsistence fishing use in the Delta

Separate from recreational fishing use, subsistence fishing provides nutritional and economic benefits to regional fishing people and communities. Fishing use can be measured by total fish consumption rates, which are also useful for understanding impacts from contaminated fish consumption.

3.Z Job-equivalents per unit of water transferred from a source region (e.g., agricultural labor force)

When water is transferred among regions, source regions may lose economic benefits from the "lost" water. A common type of source region is agriculture. When agricultural lands are fallowed with water transfers, then jobs associated with these lands may be lost.

3.AA Fiscal cost and benefit for local economy in water-source region due to water transfer

Water source regions may lose economic benefits from actively (e.g., agriculture) or passively (e.g., aesthetic enjoyment) using water. This dis-benefit will likely be realized as fiscal cost to businesses, local tax-rolls, and individuals.

3.BB Equitability of benefit realization for local economies in water-source and water-receiving regions due to water transfer

Local economies in source areas may be affected quite differently from local economies in receiving areas with inter-regional/basin transfers. Understanding how equitable these effects are on local economies may be important in understanding the overall effects of transfers.

Goal 4. Increase quantity, quality, and reliability of drinking water, irrigation water, and in-stream flows. Objectives: Increase conjunctive management of new and recycled water from multiple sources.

Indicators:

4.A Annual withdrawal of ground and surface water as a percent of total annually renewable volume of freshwater

Groundwater withdrawals and recharge are an essential part of California's interaction with groundwater as a resource for economic activities and health. How these occur and the net change in groundwater availability changes the future availability of ground water and thus sustainability of California. In a project in the Napa watershed, led by Napa County, statistically significant decline in a groundwater basin was an important indicator of sustainable water availability.

4.B Correlation between quality and quantity of available drinking water and household income

Equitable access to clean, plentiful drinking water is considered to be a human and cultural right. Ensuring that this basic right is met is a societal responsibility and helps to understand equity under the Water Plan.

4.C Use of recycled water as a percent of total water used

Re-using water reduces the demand on existing and new water sources and reduces costs associated with new water retrieval, storage, movement, and delivery.

4.D Years of average water use at current use levels represented by the current stored volume of water

Water available for human use comes from available groundwater, reservoirs, imports, expected precipitation, and snowpack. The total retrievable water at any given time may set boundaries on sustainable water use

4.E Proportion of agricultural non-potable water needs--e.g. irrigation--met with non-potable water

Agriculture is a major user of non-recycled, potable water. Increasing re-use of water and use of non-potable water by agriculture leaves a greater proportion of declining water supplies for other consumptive uses and the environment.

4.F Increase measurable benefit in in-stream flows from water recycling and conservation

Re-using and conserving water has the desired outcome of directly benefiting aquatic ecosystems. Measuring the direct benefit in terms of in-stream flows ensures that the desired outcome is achieved.

Goal 5. Safeguard human and environmental health and secure California water supplies Objectives: Protect and restore surface water and groundwater quality; Protect the natural systems that maintain these services.

Indicators:

5.A Pollutant and bacteria Index

Various agencies, states, and countries have developed water quality indices composed of multiple metrics. They tend to include physical and chemical parameters and sometimes biological parameters.

5.B Rate of Fertilizer Applied (kg/ha)

Application of fertilizers to agricultural fields can impair local and regional waterways, directly and indirectly affecting trophic state, native and non-native plant and animal species, drinking water quality, and bioaccumulation of mercury. (Also in Goal 3)

5.C Tons of industrial pollutants released and disposed of by watershed/region

Waste materials from industrial activities are discharged to waterways and landfills. Permit requirements often lead to monitoring and associated data, which can be used to understand how much pollution is released on land and water.

5.D Mercury in fish tissue

This is primarily a legacy effect of mining activities in the 19th century. Mercury in eroded soils and benthic sediments can be methylated under certain aquatic environmental conditions and end up bioaccumulated in fish tissue. High enough concentrations are present in many waterways and wetlands to harm piscivorous birds and mammals, including people. (Also in Goal 3)

5.E Periphyton cover and biomass

Attached vascular plants and algae (periphyton) are a natural part of ecosystems. Increased light availability, water temperature, and nutrient availability can contribute individually and collectively to the over-growth of aquatic plants. This bioassessment indicator has become more prevalent among water quality agencies because it reflects a combination of effects of land and water use on aquatic ecosystems.

5.F Species richness (birds, fish, invertebrates)

Example: benthic macroinvertebrate community

Similar to aquatic plants, benthic macroinvertebrate (BMI) communities provide a measure of disturbance to aquatic ecosystem. There are a number of different BMI community metrics that are useful for understanding disturbance of stream ecosystems that are commonly used around the world and the California Department of Fish and Game. The Sacramento River Watershed Program and Napa Watershed indicators projects both included BMI metrics.

5.G Ratio of observed to expected native aquatic species

An intact and healthy watershed and waterway network will tend to maintain most or all of the expected native aquatic fauna and flora over any one study period. As disturbance increases, fewer native species will be observed and this ratio will decline.

5.H Flow patterns and alterations

Ecosystems depend on natural flow patterns and variability. High flows are needed to move sediment and re-work riparian and floodplain areas. Many systems may be adapted to the shape of the hydrograph, especially the rate of declining flows, which can dictate germination and success of riparian plants. (Also in Goal 3)

5.I Surface water quality index

This index is a composite of indicators of physical, chemical, biological, and cultural attributes of waterways. The index may be used in both surface and ground-water systems and may vary between these environments. (Also in Goal 3)

5.J Groundwater Water Quality Index

As with surface waters, various entities have developed water quality indices composed of multiple metrics for groundwater quality. The metrics tend to include physical and chemical parameters and sometimes micro-biological parameters.

5.K Potential runoff from urban impervious areas

Impervious surfaces from land development accelerate and concentrate runoff during precipitation events. This runoff can be measured and modeled in advance of events.

5.L Cost of water treatment

Treating water to meet desired drinking water standards requires engineered facilities. The greater the volume and the departure of the source waters from standards, usually the greater the cost.

5.M Water Stress Index

This index is used by the global Environmental Protection Index and represents the proportion of an area or region that is over-subscribed. Total water use is divided by water supply during the same period to get an index of “local relative water use”.

5.N Water Scarcity Index

This index is used by the global Environmental Protection Index and represents the over-use of water in a region. The indicator value is calculated by “subtracting the recommended use fraction (0.4) from the ratio of total freshwater withdrawals (including surface and both renewable and fossil ground water) to total renewable water resources” (EPI).

5.O Sufficient flows and timing of flows for maintaining historically-present native fish

Native fish, including anadromous species, need in-stream water to complete life-cycles, forage, disperse, seek thermal refuge, and escape predation. These flows must also be at appropriate times of day, year and season to allow them to function naturally. This is a common aquatic ecosystem indicator in managed water systems. (Also in Goal 2)

5.P Magnitude and timing of managed system flows suitable for native riparian habitats and geomorphic processes

Healthy aquatic, riparian, and floodplain ecosystems require periodic high flow events, not just minimum flows. In managed systems, high flows can be provided at appropriate times of year and at frequencies to support dependent systems and processes. Streams and rivers support riparian vegetation, a specialized assemblage of plants that is adapted to and relies upon certain ranges of geomorphic and flow conditions. For example, natural cottonwood tree recruitment occurs when there is a gradual decline in the relative elevation of a river and its associated hyporrheic flow, but not if the decline is too rapid, as can accompany managed systems. Movement and re-distribution of sediment downstream, channel migration, bank erosion, and new land formation are all important functions of in-stream flows. These geomorphic processes are supported above certain flows in a natural system and can be mimicked to some degree in managed systems. This indicator is used in the Sacramento River Riparian Monitoring and Assessment Program, as well as other similar large-river systems. (Also in Goal 2)

Goal 6. Protect and enhance environmental conditions by improving watershed, floodplain, and aquatic condition and processes. Objectives: Practice, promote, improve, and expand environmental stewardship.

Indicators:

6.A Level of support or opposition for environmental measures, such as statewide bonds and local environmental regulation (% of population)

When voters show up to support (or disapprove) environmental measures, they are consciously changing public direction and potentially charging themselves through taxation or fees. When votes are for environmental measures, this is a direct measure of public support for stewardship and protection.

6.B Number of conservation and restoration projects

An important component of stewarding and protecting landscapes and watersheds is to enroll them in conservation programs using agreements and/or payments. Area, or proportion of watershed area, under conservation agreement is a common indicator of stewardship.

6.C Acres of preservation of existing natural habitats and restoration of degraded habitats

Protection and restoration of natural habitats has the co-benefits of support of terrestrial habitat and aquatic ecosystem processes and condition. A highly-degraded landscape will not support healthy waterways due to close physical, chemical, and biological interactions between these two watershed environments.

6.D Number of acres protected or enhanced in aquifer recharge areas

Natural recharge of underground water reservoirs may be the most cost-effective way to store and manage water. In urban and developed areas, water consumptive use is high, but so it imperviousness, decreasing the rate of aquifer recharge. Restoring hydrologic connectivity between surface runoff and underground water storage, benefits human and natural uses of water.

6.E Forest land conversion: Total acreage over time

When forest is converted to residential development, agriculture, or clearcuts, the natural hydrologic functions are lost or impaired. These functions may gradually return (decades) if land is retired and re-grows.

6.F Participation rates in local stewardship by the local stakeholders such as municipalities, indigenous people, irrigation districts, community organizations, watershed associations, conservation groups, and stewardship groups

Social science tells us that participation in stewardship planning and decision-making among diverse parties is important in developing common and politically-supported strategies and implementation. Rates of diverse party participation help predict likely successes or failures of processes at different scales.

6.G The completion of restoration recommendations and key actions during the implementation phase of the process

Actually carrying out stewardship actions is an important component of successful stewardship planning. This measure does not provide information about the ecological or social outcomes of the actions, but does take the first step of accounting for actions taken.

6.H Public awareness of source water protection

A common practice among sustainability indicator systems is to measure public awareness and support for environmental protection. This can be measured in several ways, including knowledge of environmental issues, expenditures to support the environment, and voting for pro-environment measures. When people have knowledge, they are more likely to take demonstrable action in support of environmental protection.

6.I Proportion of streams monitored periodically for streamflow, temperature, fisheries, stability

It is easier to manage what we understand. Monitoring conditions is critical to understanding how to protect natural systems. High rates of monitoring by public agency, or private organization programs suggest a high level of care and support for stewardship. It also leads to a greater understanding of the locations for stewardship need and the effectiveness of actions.

6.J Ecosystems and species at serious risk from unnatural fire regimes

In California, most plant community and ecosystem types have adapted to certain ranges of fire frequencies, extents, and severity. Changes in fire ecology can change native ecosystems and may eventually pose risks to human communities and ecosystem services.

Goal 7. Integrate flood risk management with other water and land management and restoration activities. Objectives: Improve land-use/cover to reduce flood risk; Improve floodplain-channel connections

Indicators:

7.A Extent of floodplain restoration and connection between channel and floodplain
Re-connecting channels and floodplains is an active area of restoration that benefits aquatic and terrestrial habitats, plants, and animals. Both the absolute amount of protection and restoration and the proportion of the historic area are informative (e.g., number of acres restored by type of habitat: floodplain, riparian, marsh, etc).

7.B Frequency of levee breaks in the region
Levees may weaken and fail over time, putting floodplain development at risk. The frequency of levee weakening and breaking is informative about the power in the channel in particular locations and the potential need to replace or move particular levees.

7.C Levee System Integrity Index (stability, risk prevention, maintenance)
Several indicators of levee performance can be combined into a single index. When combined with the cumulative hydrostatic force, an overall indication of the likelihood of levee failure could be obtained.

7.D Building standard and cost of maintaining levees/assessed value of the land use they protect
Levees must be maintained and occasionally strengthened to provide consistent flood-protection to lands in the floodplain. The ratio of incremental and cumulative costs of maintaining levees and the value of development protected by the levees provides a form of cost-benefit analysis for levee maintenance and prioritization.

7.E Expected annualized damage for flood risk
Although actual costs from flood damage cannot be determined in advance, the projected cost of repair and replacement can be modeled for different flooding scenarios. These costs are likely to be borne by multiple types of organizations.

7.F Proportion of watershed covered with impervious surfaces, including pavement, buildings, and turf grass
As the developed, impermeable surface area in a watershed increases, so does the risk of downstream flooding and channel incision. By constructing new roads, houses, and other rural and urban development with high permeability rates, risk of flooding can be

decreased. These changes and accompanying changes in management of the water path may change flood risk.

7.G Proportion of floodplain that is protected from development that is incompatible with flooding

Conserving and restoring floodplains can have profound effects on the risk and effects of flooding, depending on the proportion of the historic or contemporary floodplain that is affected.

7.H Cumulative hydrostatic force

This indicator was proposed during a CALFED-sponsored review of the Delta levees program (Mount and Twiss, 2004). It represents the calculated force that rivers in flood put on segments of levee.

Goal 8. Support decision-making, especially in light of uncertainties, that support integrated regional water management and flood and water resources management systems. Objectives: Improve and expand monitoring, data management, and analysis

This objective is proposed to complement the other sustainability objectives that are based primarily on CWP-2009 Objectives and Resource Management Strategies. It deals with measuring whether or not the science and management systems themselves are responsive to existing and changing conditions. It supports the idea that sustainability is a process, as well as the result of a series of conscious actions.

Indicators:

8.A Flow chart of process from data need, collection, analysis, decision-making, implementation, and results

Formally anticipating and retrospectively tracking the flow of information from need to decision outputs allows for greater understanding and improvement of management processes.

8.B Process/data needs of local jurisdictions and geographies

Participation of local government entities in measuring conditions and performance contributes to better decision-making. Similarly, specific needs for more information, or improved information flow may vary from one location to another. Understanding these needs will benefit regional integration of local activities.

8.C Public reporting system for data and results of analysis as well as methods used

Society expects a certain amount of transparency in agency decision-making, especially when it affects them individually, or collectively. Transparency occurs when information is both readily available and understandable to individuals, or their trusted representative. Controversial decisions are less likely to be challenged if the pathway to the decision is transparent and clear.

8.D Standardized methods for data collection and reporting and minimize collection biases

A common problem in synthesizing data to measure performance of complex systems is the lack of data format and data collection standardization among entities, even for common metrics. There is a similar lack in data sharing, sometimes within entities. A large agency, group of agencies, or more diverse partnership is more likely to understand, predict changes, and be able to sustain complex systems if basic data standardization and sharing protocols are developed and followed.

8.E Data sharing and distribution

Monitoring sustainability is most easily done when metrics and indicators are readily understood. This is made easier when data are easily shared. When systems are created to facilitate data distribution, they are more likely to be understood and management is more likely to be based upon these data.

8.F Communication of uncertainty

One predictable outcome of increasingly constrained managed systems and climate change effects is an increase in the uncertainty of predictions of how these systems will function. It is important for scientists and analysts to communicate this uncertainty so that it becomes useful information in management decision-making and policy formulation. This indicator refers to both the act of communication and the nature and content of communication. In other words, just narrative descriptions of uncertainty may be an insufficient level of information for many types of management decision-making, but may be sufficient to build responsive policies.

8.G Collaboration between scientists and policy makers to understand data and communication needs

Each of these types of public servants serves a different and special role in developing sustainability. Acting together, they are more likely to develop decisions that reflect the best information AND the desires and needs of society.

8.H Supports adaptation and resilience to climate change

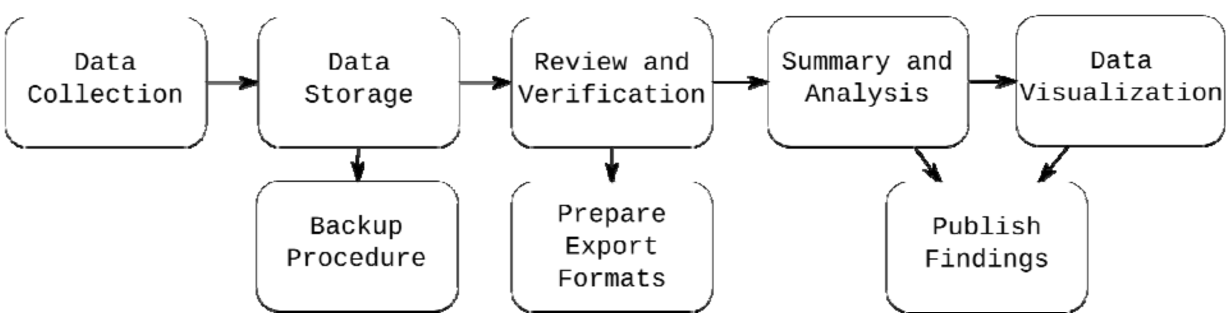
In order to allow for rapid and anticipatory responses to climate change effects, both the decision-making and information collection/analysis process should be designed to be flexible and adaptive to new conditions.

Appendix E Scientific Workflows

Scientific workflows offer both a theoretical as well as a practical way for building a comprehensive environment for data management, analysis, and decision support. Scientific workflows combine scientific data and process workflows, and provide a graphical interface to manage the pipeline of steps of a scientific problem (Ludäscher et al 2009). One can think of scientific workflows as similar to a flowchart, where the various nodes represent computational tasks and the lines connecting each step are the data inputs and outputs for each step. Each step can either be automated, such as a number crunching analytical task, or semi-automated, where external input and responses are required to complete the steps. A graphical interface allows for the chaining of the these tasks by managing the input and output of data between processes (Davidson et al, 2007).

Flowcharts are used in every industry to diagram process or business workflow. These illustrations are an excellent way of educating people about system processes, and they also provide excellent reference material for training and documentation. They can also be used to ensure certain steps are not omitted during a series of repetitive steps. While business workflows are based on business processes, scientific workflows are driven by data, and manage the data inputs, outputs, and transformations at various stages of the workflow (Bowers and Ludäscher, 2005). End-to-end data management practices can be incorporated into a scientific workflows, including data collection, storage, backup, retrieval, and analysis, and visualization. This explicit handling of the data management activities ensures that processes can easily be duplicated, and since it is a working workflow diagram, each step can also be well documented.

Scientific workflows provide an overview of the scientific problem broken down into its tasks and subtasks. From the data collection phase to data visualizations, a scientific workflow conveys these steps to the researcher so that each task in the process to each a completion of the scientific problem is well documented (Howe et al., .2009).



Scientific workflows offer a different way of looking at computation and data management. In a traditional model, the programmer schedules the execution of the control flow, and the system executes the specified procedures and functions. In scientific workflows, data transfer drives the computation. When the processes are connected to form a larger system, an executor initiates the workflow, and the flow of data initiates the pipeline of singular and parallel computational processes.

Scientific workflows, like social networks, are directed graphs where the nodes represent discrete computational components or process workflow steps and the edges represent results (data) which become the input parameters of the next node. Scientific workflows can be fully automated computational graphs, or semi-automated graphs with user inputs and human-based processes added (Ludäscher et al 2006).

Data Provenance in Scientific Workflows

A prominent feature to scientific workflows is how data provenance can be captured within the workflow. Data provenance refers to the origin of data, how it is managed, and how it is used for decision support. Scientific workflows explicitly provide these provenance pathways as edges in the directed graph. Each edge represents data flow, which have certain attributes and constraints that link the processes together. These dependencies define the provenance of data within the system, as they explicitly define the state of the data before they are consumed by the next step in the process (Davidson and Freire, 2008).

Data can undergo numerous transformations before it is stored in a database or data warehouse. *Data lineage* is the process of tracking the evolution of data, from the time of collection to the time of long term storage (Widom 2005). *Data provenance* documents how data was transformed so that reconstructing the original version of the data is possible. Data models need to include both provenance and lineage information so that researchers can query these metadata to understand the history of a data.

Scientific workflows can also be a good tool for documenting the lineage of the data, within the system. The data lineage includes where it comes from, what it is used for, and how it is transformed, at the various stages of the workflow. At any point in the process, it should be possible to recreate the exact state of the data.

Scientific workflows organize computational tasks, similar to a computer program, but they provide a user interface that allows researches--not just computer programmers--to understand better the scientific processes and data transformations used to solve the problem. The scientific method calls for a transparent handling of data and analysis so that the research community can replicate experimental results. Scientific workflow provides an excellent delivery mechanism of these results, where the visualization of the findings is joined with the methods performed to acquire data.

Building an indicator framework with Scientific Workflows

Each indicator within a framework has its own data management requirements. The data sources of often disparate, the techniques to transform and analyze the data are unique, and the visualization of these data depends on the environmental phenomenon being analyzed. Essentially, each indicator has its own scientific workflow.

While each indicator is different, they share many similarities. Each needs to collected data for analytical processing which leads to a result that allows managing stakeholders a means to make decisions. This often involves a visualization (graph), a summary of recent trends, or a comparison with other similar indicators. Therefore, once a scientific workflow is developed for an indicator, there is a strong possibility that the core structure of the workflow can be reused. Each workflow would essentially become a template for other indicators which perform similar tasks.

The ability to examine the data provenance within an indicator framework is critical. If decisions are made based on a particular analysis, having the ability to trace back to the data transformation can help verify those decisions. This can ensure a level of transparency in the decision making process, which is essential for indicators where grades or ratings are assigned to an environmental condition.

Scientific workflow processes can be integrated with online mapping components. The Open Geospatial Consortium (OGC) Web Feature Service (WFS) can be linked to workflow processes so that the generation of maps, an excellent visualization tool for the environmental sciences, can integrate into the workflow (Best et al. 2007).

There are several software applications to develop scientific workflows, including Kepler, VisTrails, and Taverna Workbench. Kepler and Taverna are written in the Java programming language, while VisTrails is written in Python. While building scientific workflows is still the task of a data modeler or programmers, some of these tools are making it easier for data analysts and project managers to participate in the workflows construction. There is a strong indication that these applications will continue to develop, perhaps to the point where such workflows can be modified over the web by decision makers, and provide specific tools for decision support.

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Appendix F Sustainability Indicators Reporting Framework

Introduction

Sustainability indicators provide easy-to-understand measures of the status and health of the environment, society, and economy. The status of parts of these systems can be presented as normalized values between 0 and 100, where higher values equate to a healthier, sustainable state. But while an indicator value can be easy to comprehend, the analytical methods, data management, and relationship between the raw parameters and the indicator framework is not as straightforward.

Proposed here is a reporting system to complement the indicators framework which would provide decision makers and interested citizens a view of the state of the environment and human systems through an easy to use interface. In addition, the reporting system would provide the essential provenance pathways so that the methods used to arrive at the indicator values can also be investigated and understood. This "drill down" ability would provide the sources of data used to calculate the indicator value as well as a description of the analytical methods used to calculate it.

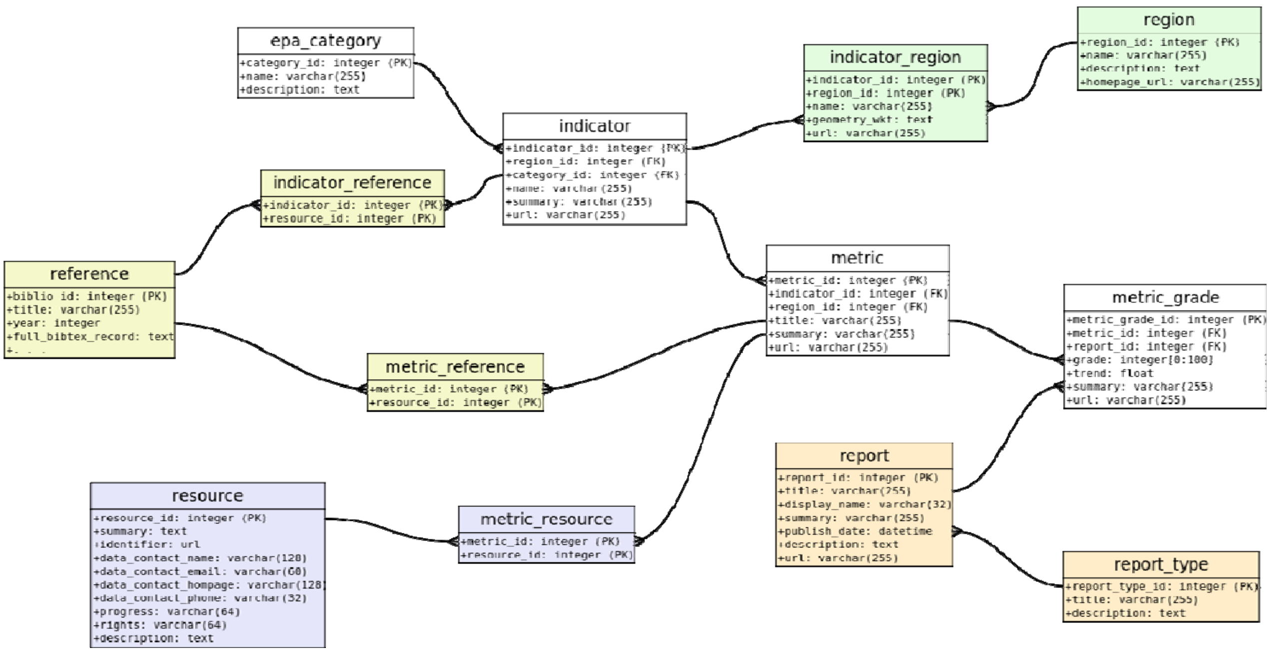
Architecture

The system would be a web-based information system, with both a relational and a spatial database back-end. While other tools could be used to build this system, a python-based web-application framework is proposed, with a PostgreSQL and PostGIS database back-end. Web mapping would be a core component of the system, where the spatial extent of the indicator value would be represented on a map, and would enable the user to navigate the map interface to view and retrieve other indicator values across space.

The indicator system would track all aspects of indicator development. It would contain a database of indicators from other projects so there is a link between California indicators and those used in other studies. It would link to the reports in which those indicators are used, so the decisions to build an indicator will have various authoritative sources. Therefore, the corresponding information about the data sources, the geography, the decision to choose one indicator over another, and a myriad of other connecting details should be part of this system. The development of the indicator can be just as important as the final result, or score, so all these details should be tracked within the system.

Indicators Data Model

The following data model shows the relationships for the proposed reporting system. Indicators are an abstract data type, and are at the core of the relational model. Indicators will have both properties and methods, although with this data model, only the properties are shown. This includes relationships with the goals and objectives of the indicator, the spatial extent (or regions) that the indicator is relevant, the analytical technique to generate the indicator value (internally called metric), the indicator report (reference) where the indicator is described, and the data resources used to calculate the value.



In building an online indicator system, there are many ways to approach the problem. The online system can be a simple reporting tool, or a more sophisticated decision support system (DSS). While the online DSS would take more effort to build, it would also provide more flexibility and allow the indicators to be manipulated online rather than external to the web application. It is possible to start with a simple reporting system, but it is advisable to design the application in a way that it could be expanded to a true DSS.

Static Indicator Management

Static indicator management is where a person must enter the results of the indicator analysis manually into web-based forms. The values get stored in the database, and are displayed at relevant times, such as on the regional indicator map, the indicator page, and in various reports. The analysis is external to the web application. The system is used to collect the results, but there are no mechanisms within the web application to change the underlying input values which generate the scores, and have the system update automatically. All the modification must be done by a data manager, and if the system becomes large, the data input requirements could be overwhelming.

Dynamic Indicator Management

A more sophisticated indicator management system enables the user to make changes to indicators online. A dynamic system becomes much closer to a true DSS as it would allow the user to combine indicators to create new indexes, adjust the distance-to-target values which would adjust the indicators score, and allow indicators to be recalculated automatically as new data is being added. The system would interface with the R statistical program in which certain indicator status and trend scores are generated. The system would require a data manager to setup new indicators, link to data sources, and build the necessary R programs to analyze the data (these steps are still necessary in a static model, but they are never linked to the indicator system). Once the system is setup, it would calculate the indicator scores automatically so the data entry requirements would be minimized.

Appendix G Ecosystem Services and Sustainability Indicators

There is a lot of overlap between sustainability indicators and measures of ecosystem services. To be sustainable, societies would recognize and protect services provided by natural systems that would be either impossible or expensive to replicate. Because of this, further discussion of measuring ecosystem services is provided below.

What ecosystem services are

Nature provides multiple benefits, also called ecosystem services, to humans. These include tangible services such as food and resources – fish, crops and freshwater, but also other less recognizable benefits including flood protection, erosion regulation, water purification and spiritual and cultural fulfillment. All these services, directly or indirectly, contribute to human well-being (MEA, 2005).

There are debates in the scientific literature about appropriate theoretical constructs to capture the essential attributes of ecosystem processes, services, and benefits (figure 5), while making sure the constructs are accessible and useful to land managers, land-owners, and agencies (Boyd and Banzhaf, 2007; Fisher and Turner, 2008). Superficially, some of this debate may seem about semantics (e.g., is pollination an ecosystem service, or is the food production from pollination the service?). However, as Wallace (2007) points out, terminology and logical and intuitive frameworks are keys to operationalizing the accounting for and protection of ecosystem services.

Ecosystem services can be quantified in their native units (e.g., tons C sequestered), and evaluated on the basis of their separation from the “ideal point” (Malczewski, 1999). Thus service/benefit values are re-scaled by comparing to a desired measurable condition, as implied by objectives for the system.

Ecosystem services/benefits outcomes can also be aggregated and incorporated into an overall assessment of categorized services/benefits for a geographic reporting area. This step is not essential to quantifying services, but helps in evaluating progress toward goals and objectives, or aggregate value of an area of the landscape. Additive forms are one aggregation process, but is not the only one and not appropriate when services/ benefits are not independent (Keeney and Raiffa, 1976; Zeleny, 1982). In this case, the less restrictive weak-difference independence condition is necessary for multiplicative and multi-linear functions (Butler et al., 1997 & 2001; Thurston, 2001).

Consideration of ecosystem services in the Framework will be substantially based upon approaches and uncertainties identified as critical by the Millenium Ecosystem Assessment (2005). These include relationships between process and rivers across scales, the relative linearity of changes in ecosystem function in response to drivers, market and non-market valuation methods for services that can link ecosystem processes to benefits to people, modeling changes in services across likely landscape-scale scenarios, incorporation of human behavior to improve quantitative modeling and decision-support, cross-scale linking between services and (who) benefits, and effective communication with non-technical decision-makers. The MEA has much in common with more detailed ecosystem service evaluations in agricultural systems and in the West (figure 1).

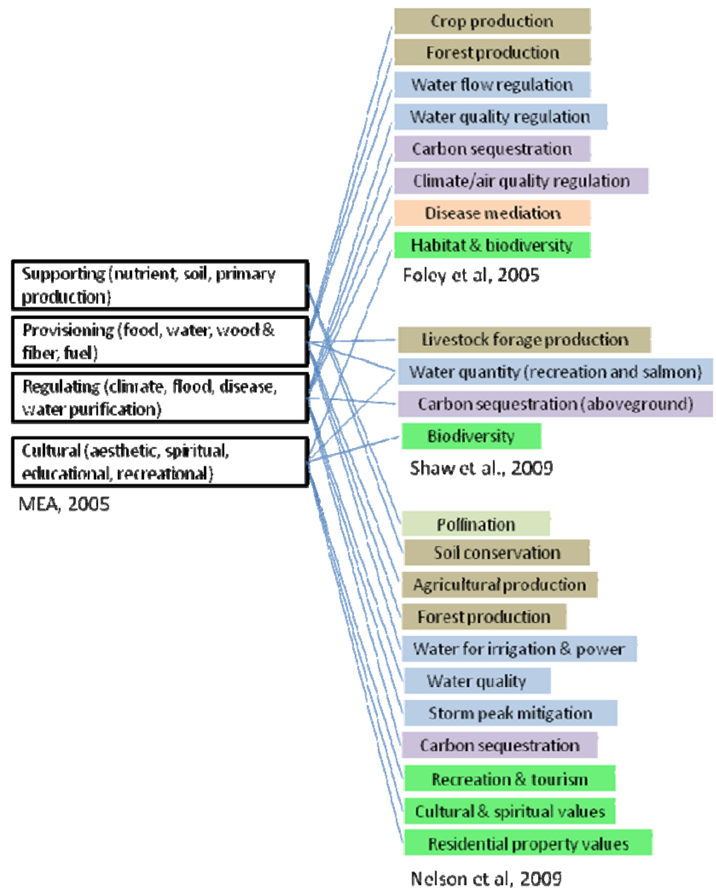


Figure 1 Cross-walk among the Millennium Ecosystem Assessment (2005) ecosystem services categories and those from 3 recent evaluations of ecosystem services in global agriculture (Foley et al., 2005), Oregon's Willamette Valley (Nelson et al., 2009), and California's rangelands (Shaw et al., 2009).

Market opportunities exist for ecosystem services, often described as "payment for ecosystem service" (PES). PES programs are negotiated contracts with landowners to maintain a certain level of environmental performance to maintain or enhance ecosystem services (examples: Forest Trends and Ecosystem Marketplace, 2008). Developing ecosystem indicators and metrics and tracking project impacts using those measures can make it easier to access any operating regional ecosystem markets and if ecosystem markets are available and if metrics were developed, then system for ecosystem measurement should be well-suited to ecosystem market use.

Ecosystem markets present various benefits for infrastructure agencies:

- First, it removes the risk of uncertainty of the project linked to the needed approval by environmental agencies. Projects are often slowed or stopped by deficient environmental analysis like the Environmental Impact Report (EIR) required by federal and state laws: National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), or the Clean Water Act.

- Second, ecosystem markets include a transfer of liability: the liability for the restoration or conservation success is placed on the banker and not on the infrastructure agency.
- Third, this system produces a better alignment of mission since instead of water engineers, restoration professionals build the ecosystem service projects.
- Fourth, ecosystem market may produce improved ecosystem outcomes because bankers can have more comprehensive and meaningful projects to address ecosystem priorities.

But although PES systems have great potential power for ecosystem preservation, there are still major criticisms (Redford and Adams, 2009), including the risk that economic arguments about services valued by humans will overwrite and outweigh noneconomic justifications for conservation and the concern that there is no clear way to track the performance of the system. Therefore, ecosystem service markets must be only one of several tools aiming at preserving ecosystems.

All the major ecosystem services can be classified in four main categories according to the Economics of Ecosystems and Biodiversity (TEEB) system (Table 1):

a. **Provisioning services:** the goods and products obtained from ecosystems, which include crops, timber, and livestock as well as genetic resources for medicines.
b. **Regulating services:** the benefits obtained from an ecosystem's control of natural processes, in other words, from maintaining a healthy functioning ecosystem. These include water regulation and climate regulation.
c. **Supporting services,** the natural processes that maintain other ecosystem services, including nutrient cycling, water cycling, primary productivity.
d. **Cultural services,** intangible and non-material benefits people derive from nature, such as spiritual and aesthetic benefits as well as recreation and tourism.

Why indicators of ecosystem services are necessary

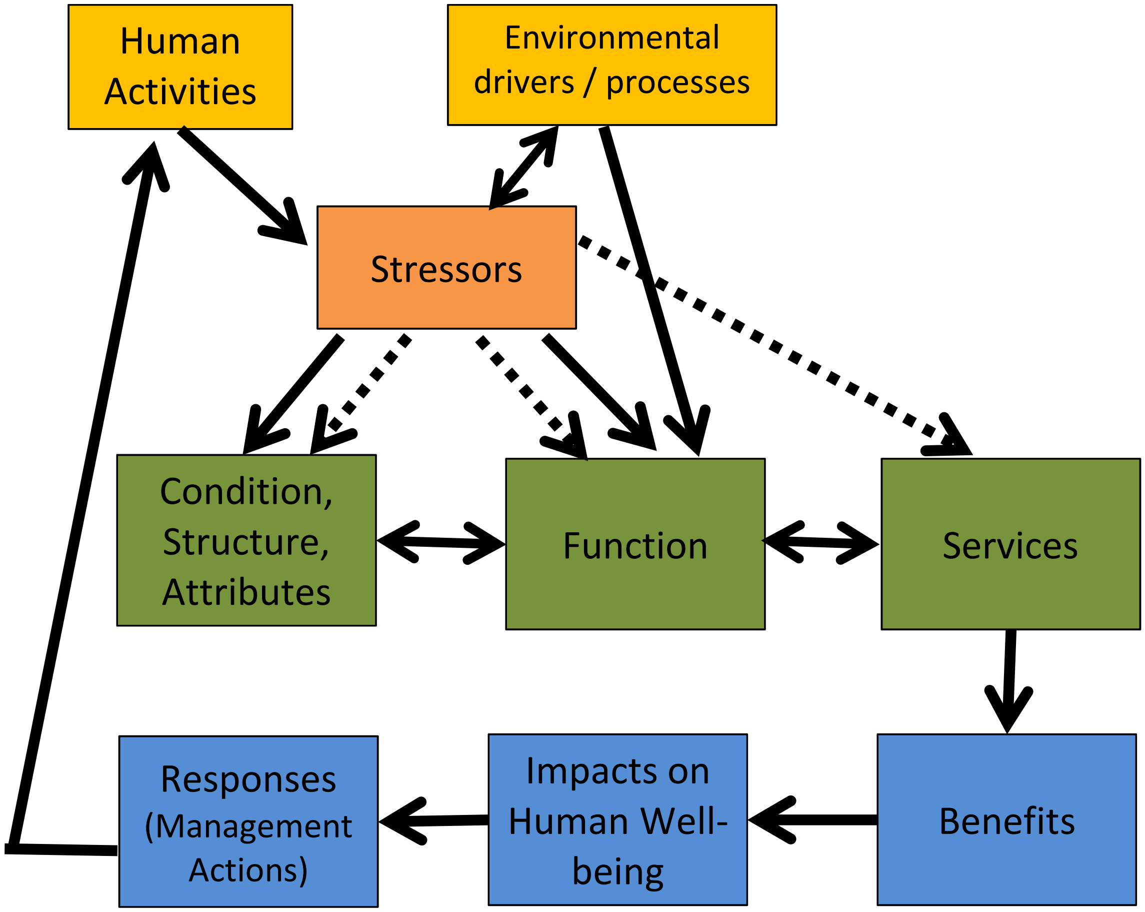
The Millennium Ecosystem Assessment, a worldwide study of the state of the world´s ecosystems, reported that 60 percent of ecosystem services were impacted and emphasized the importance of evaluating ecosystem services and the need to monitor them to achieve sustainable development (MEA 2005, Carpenter et al. 2009). In order to reverse current trends of ecosystem degradation and to become more sustainable, it is an urgent priority to integrate ecosystem service considerations into mainstream economic planning and development policy at all scales. Ecosystem service indicators can be used as tools for communicating the value and condition of ecosystem services to policy-makers and help them integrate this information with social and economic indicators.

How ecosystem services are provided

Natural systems and their elements are highly interconnected. The water cycle represents a good example of how ecosystem structure and processes provide services and benefits to people (Wright and Johnson 2011). Water is found in diverse forms and locations (streams, atmosphere, groundwater), each having a specific structure defined by biotic and abiotic attributes. Various processes (precipitation) and external environmental drivers (climate, geology) act on this ecosystem structure and on its specific functions (infiltration) to make water available and to move through the system. This ecosystem functioning allows the flow of energy among biotic and abiotic elements and continuously provides ecosystem services. Humans derive benefits from the use of water through direct consumption, through its living resources or after enjoying aquatic recreation activities. Additionally, people also benefit indirectly from ecosystem processes including water flow regulation or water infiltration. However, humans also modify the condition of water, the landscape and the biodiversity found in natural systems, which has an effect on the ecosystem functions and the services associated with them. A negative impact on ecosystem services can lead to the promotion of management actions and responses, which could restore, maintain or enhance the structure, condition and function of the natural system and consequently the services that depend on them.

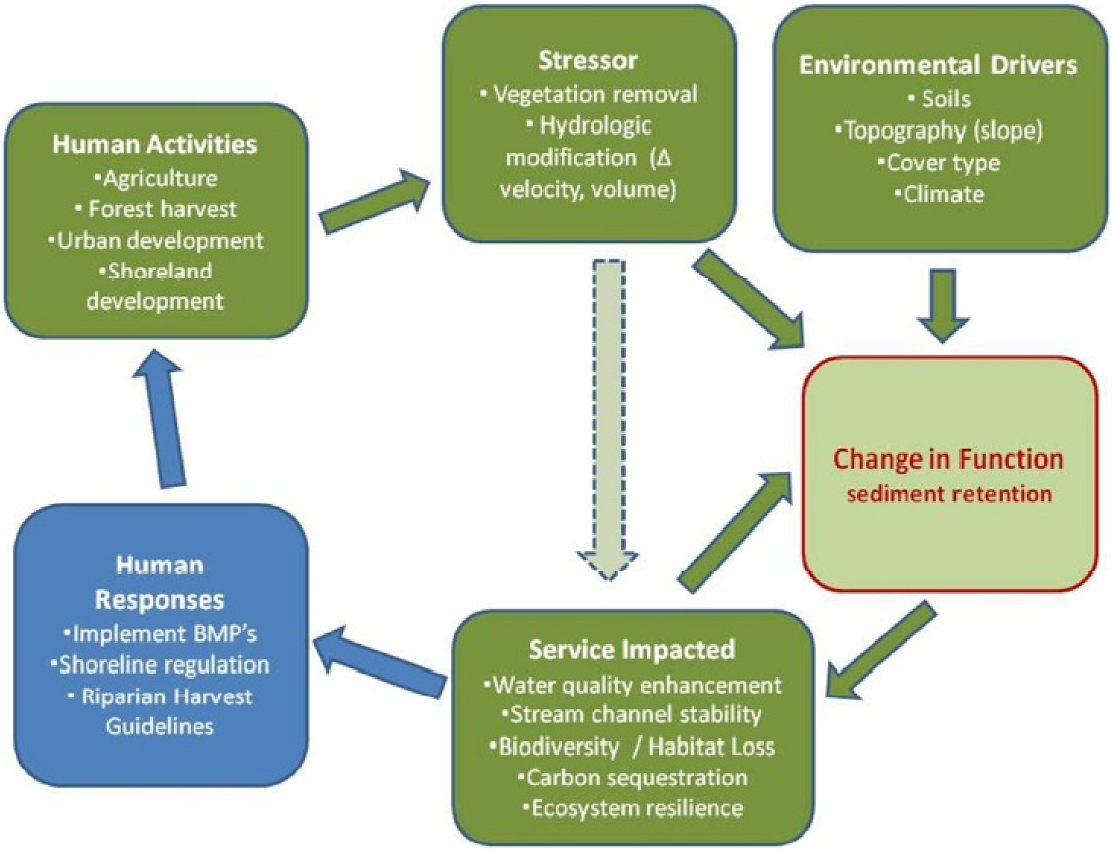
There are complex interactions which comprise ecosystem services (figure 1). The provision of ecosystem services involves complex dynamics and interactions among the different elements, processes and functions of the system. An ecosystem function can be associated to multiple services and the strength of these associations could vary depending on the system conditions and external influences. Figure 2 illustrates an example of these interactions related to sediment retention as an ecosystem function.

Figure 1. Model of ecosystem services provision



Based on Wright and Johnson 2011, UNEP-WCMC & WRI 2009

Figure 2. Sediment retention stressor-function-service-response diagram



Taken from (Wright and Johnson 2011).

How to integrate indicators into an ecosystem service framework

The goal of ecosystem service indicators is to inform about the characteristics and trends in ecosystem services. Ideally, these indicators should provide information about the *flow* of service— the benefits people receive (Layke 2009). However, indicators of flow of service are not always easy to implement due the difficulty in measuring the flow of benefits from some regulating and cultural services (Feld et al. 2007). Therefore, in some cases it is necessary to rely on proxy indicators, which are substitute measures when it is not possible to measure the service directly. In the context of ecosystem services, examples include the amount of nutrient removed from agricultural runoff by wetlands (as a measure for nutrient retention and water regulation), and number of people visiting natural areas (as a measure for spiritual services).

A key first step in the development of an indicator system to assess ecosystem services is choosing the framework or conceptual model that the system will be based on. As flow of service - represented by the actual flow of benefits derived from the ecosystem service- is the goal to be monitored, frameworks including benefit models should be preferred (Layke 2009). One example of this conceptual framework is the *Benefits Model Building* *on the Ecosystem Services Framework* (Balmfordet al.2008, figure 3). In this model, services directly enjoyed by people are identified as "benefits" while services that provide these benefits are termed "processes". In addition, benefits mostly include provisioning and cultural services while beneficial ecosystem processes include mostly regulating services (with water provisioning a notable exception). This example illustrates that there could be differences in interpretation and definition of the framework components when trying to measure benefits from ecosystem services. A conceptual framework for ecosystem services like the one included in Figure 1 differentiates between ecosystem processes, functions and services. However, when the objective is to operationalize the framework with indicators that are required to capture the flow of benefits derived from ecosystem services, the need to assess and clearly define these categories or components becomes more evident.

A team of experts working collaboratively on ecosystem service indicators since 2008 recommended a framework based on the following 5 components in order to identify flow of benefits and select indicators to measure them (UNEP WCMC& WRI 2009):

a. **Condition-Structure**: the ability of ecosystems to support ecosystem processes and deliver ecosystem services
b. **Function:** the processes by which ecosystems deliver services and benefits. Most regulating and supporting services can be ecosystem functions in this classification;
c. **Service:** ecosystem products that are important for supporting human well-being, but not directly consumed by people. For example, freshwater that is used for irrigation or aquaculture is classified as a service since the freshwater supports peoples' livelihoods but is not directly consumed;
d. **Benefit:** tangible products from ecosystems that humans directly consume. For example, fish produced by aquaculture would be classified as a benefit. Could be expressed in physical or value terms.
e. **Impact or Outcome:** indicators of the state of people's physical, economic, social, and spiritual well-being.

An example of the indicators proposed according to the UNEP- WCMC and WRI (2009) suggested framework is included in Table 2.

Current development of ecosystem services indicators

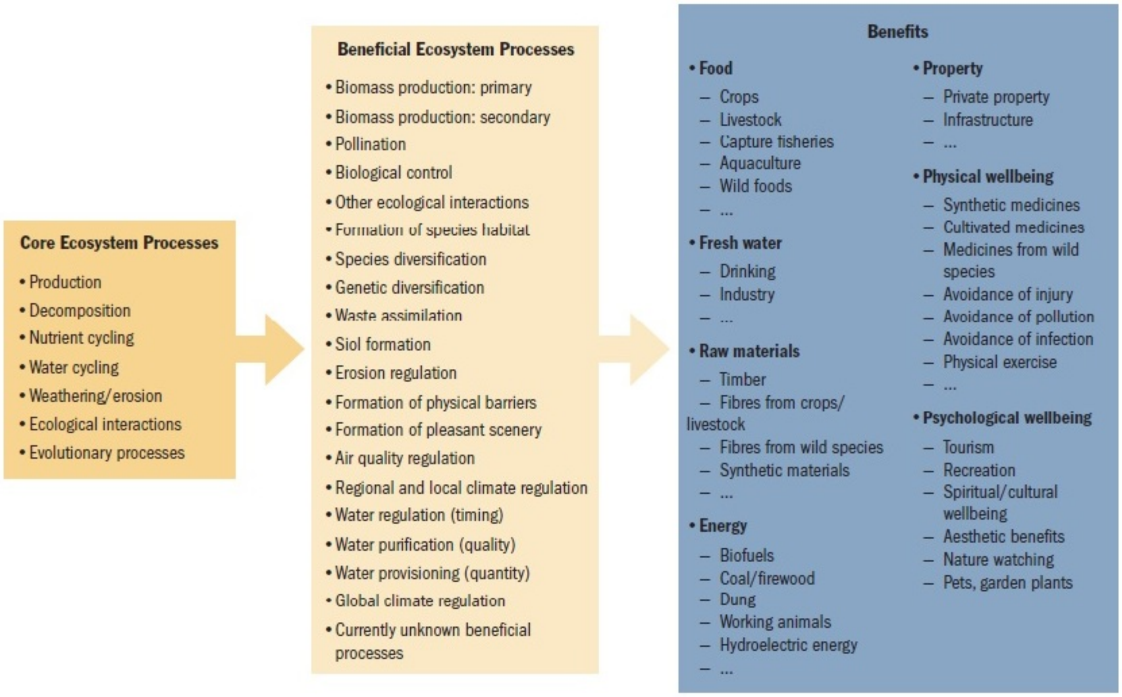
Ecosystem service indicators are relatively new tools to assess sustainable development. Frameworks, conceptual models and measures are being developed and evaluated for different topics, ecosystem elements and geographical areas. Two of the main issues that require further attention are finding the appropriate indicators that directly measure benefits flows and better understanding how indicators can adequately capture the interactions among system components and services. At the international level, there are currently efforts to develop and select indicators for ecosystem services and to compile an online ecosystem indicator database that can be used for policy-makers, resource managers and ecosystem assessment teams. The World Resources Institute (WRI) with the support of the UNEP World Conservation Monitoring Centre (UNP-WCMC) is leading these initiatives.

Table 1. The Economics of Ecosystems and Biodiversity (TEEB) classification of ecosystem services

Definition	22 Service types
Provisioning	1 - Food
	2 - Water
	3 - Raw Materials
	4 - Genetic resources
	5 - Medicinal resources
	6 - Ornamental resources
Regulating	7 - Air quality regulation
	8 - Climate regulation (including carbon sequestration)
	9 - Moderation of extreme events
	10 - Regulation of water flows
	11 - Waste treatment
	12 - Erosion prevention
	13 - Maintenance of soil fertility
	14 - Pollination
	15 - Biological control
Habitat/Supporting	16 – Maintenance of migratory species
	17 – Maintenance of genetic diversity
Cultural [provide opportunities for:]	18 - Aesthetic enjoyment
	19 - Recreation & tourism
	20 - Inspiration for culture, art & design
	21 - Spiritual experience
	22 - Cognitive development

Source: Groot et al 2009.

Figure 3.Benefits Model Building on the Ecosystem Services Framework



Source: Balmfordet al.2008

Table 2.Example of indicators proposed according to the UNEP WCMC and WRI (2009) suggested framework

	Condition	Function	Service (Use)	Benefit (expressed in physical or value terms)	Impact
SUPPORTING SERVICES					
Gene pool protection	Number of livestock breeds Number and share of (OR: Population size / percentage) of (native) livestock breeds that are endangered Number of crop varieties	Hectares of land in traditional varieties; Number of breeding females / animals within each species.		Number of disease resistant or tolerant livestock breeds or crop varieties	Avoided erosion of the genetic resource base Resistance to diseases
REGULATING SERVICES					
Climate regulation	Carbon stock (vegetation, soil, water bodies)	(Sustainable) net carbon storage/Net carbon storage (Tc/time unit); Net sequestration net balance between ecosystem carbon gains and losses, also size of stocks in vegetation, soil and water bodies.			Avoided economic damage, bodily harm, livelihood damage, etc. as a result of climate change mitigation

Source: UNEP WCMC & WRI 2009

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Appendix H Ecological and Water Footprint

In Phase II of the Sustainability Indicators project, a water footprint will be developed for California regions. The water footprint is composed of water use/impact indicators and is thus an index of water impact. Because of its potential role in implementation of the Sustainability Indicators Framework, a more detailed description of how footprints work is provided below.

An ecological footprint is a measure of the impact humans have on the earth. In the simplest terms, it is a measure of resource consumption and waste production compared with the planet's natural ability to generate new resources and absorb waste. An example of just one facet of an ecological footprint is the use of trees for construction or paper production. The use of trees not only results in extraction of wood/pulp in the form of logging of forests, energy use, and land use change, but also in the production of waste in the form of landfill pollution.

According to the Global Footprint Network, humanity's ecological footprint is greater than twice the size it was in 1966. With a footprint this large, societies on earth require more than 1.5 planets to support life as we know it. Furthermore, the earth's ability to regenerate the amount of material humanity uses in a year takes 50% longer than the time it takes to consume the same resources. It is projected that in 2030 our need for resources will equal two planet Earths to maintain our current rate of consumption. Although there are global estimates for humanity's overall ecological footprint, countries differ in their contributions, measured in terms of consumption and biological capacity (the ability to regenerate natural attributes). Under the ecological footprint system, the combination of consumption and biological capacity results in either an "ecological credit" or an "ecological debt" measure for each country. Most countries in the world are currently operating as ecological debtors, using more resources than can be replaced in the same amount of time (Global Footprint Network 2010). In fact, while humanity's demands have been rapidly increasing, many countries are outsourcing resources (World Wildlife Fund 2010).

The Water Footprint Network developed a global water footprint standard that contains definitions and calculation methods for determining water footprints for different purposes and scales. The assessment contains four steps: Setting goals and scope, water footprint accounting, water footprint sustainability assessment, and water footprint response formulation. There are different types of water footprints: the water footprint of a product, consumer, community, national consumption, business, and any geographic area. The level of detail needed for data as well as the frequency of measurements depends on the spatial scale assessed.

Without understanding the level of input vs. outputs in our water cycle, we cannot grasp if, as a society, we are prepared for future population growth and the needs of humanity. The WWF estimates that although 1.8 billion people in the world have access to internet, 1 billion still do not have access to freshwater (World Wildlife Fund 2010). It is important to link water use to indicators that are both internal to a region (e.g. agriculture, consumed goods, energy, and land use) as well as external (e.g. imported products and services that use water outside the region either directly or indirectly). The indicator framework provides indicators that will help California measure its water footprint and ecological footprint. Measurements of ecological integrity, flood risk, land use, pollution, recreation, groundwater, and cultural uses, in addition to water use and quality in both the short and long term all contribute to our overall understanding of the water footprint and by extension ecological footprint.